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STUDY OF THE MOON AND PLANETS BY SPACECRAFT

by G. A. Skuridin

"Znaniye" Press, Moscow, 1971

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By G. A. Skuridin

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ANNOTATION

The author tells in the present brochure about the scientific problems which stand before scientists and the designers of the devices directed into outer space for the investigation of the planets of the solar system. This booklet is devoted to the recent achievements in the investigation of the planets by spacecraft.

The results of the investigations of the atmospheres and ionospheres of the planets nearest to us, namely, Venus and Mars, are discussed in the greatest detail, and the physical and mechanical data on the Moon obtained as a result of the flight of Soviet and American automatic spacecraft and space ships are expounded. The prospects for the study of the planets of the solar system are absorbingly and interestingly related in this booklet.

The author expresses his sincere appreciation to Professor V. I. Moroz and to Candidate of Geological-Mineralogical Sciences A. A. Gurshteyn for their comments and advice, which assisted in improving the present booklet.

Don't just live —
live with enthusiasm!

S. P. Korolev

CUMULATION OF TECHNOLOGIES AND SPACE RESEARCH

The early years of the space age have become a grandiose, and in fact, fantastic epoch of human daring unprecedented in its sweep and unique in its scientific-engineering results.... /3*

The first artificial earth satellite, flight to the Moon and the transmission to Earth of photographs of its invisible side, the soft landing on the lunar surface, lunar satellites, flights to Mars and Venus, the smooth descent in the atmosphere of Venus by automatic spacecraft and the landing on the planet's surface, the flight of man in space, his emergence into open outer space, the automatic docking of spacecraft and their combined flight around the Earth, the circumlunar flight of automatic spacecraft and their return with atmospheric entry at the escape velocity, the creation of a manned space station, the flight of man around the Moon, the landing of an earth man on the surface of the Moon, the return of lunar soil from the Moon to the Earth by automatic methods, and the establishment on the Moon of the first moon crawler spaceship, Lunokhod.

No single epoch has known such a grand upward flight of science and engineering! One can state with assurance that the life which has arisen on the Earth, indestructible by the force

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*Numbers in the margin indicate pagination in the original foreign text.

of its development, has made our planet not only the cradle of Reason but, having overcome the terrestrial scales, has been brought in the most recent decades to the other planets and (this is not a fantastic dream) makes them the original continents of human activity. Each stage of mankind's development is a fixed sum of the technologies, but on the whole it is an infinite series of developments: from the primitive ax to ... the reorganization of the solar system, the discovery of new solar systems, the control of the Sun's thermonuclear energy, and the creation of planetary continents.

When the first space rocket was delivered to the launching site, when its first stud was made and the first artificial earth satellite appeared in space, the people who created the rocket and the satellite from this moment on did not belong only to the Earth — their reason had burst forth into the spaciousness of the universe, and from this moment there began a new history of the solar system and a new stage in its development, but now with the participation of a man born on the Earth. /4
A new powerful factor, namely, human reason with its sum of technology accumulated during all the preceding history of human development up until this time, now entered into interaction between the Earth and the remaining objects of the solar system, which up until this time was controlled only by the natural laws of motion. From this moment, the scale of the Earth was changed, and the interaction of man and the universe was altered. In this fact lies actually the greatest value of the launching of the first artificial earth satellite.

Space flight is the indestructible dream of mankind. Centuries of agonizing meditations on the surrounding world and universe have passed. Without telescopes and any kind of engineering, not yet knowing the laws of motion and radiation, the

great pioneers of the science of the universe established the laws of a materialistic world outlook just on the basis of visual observations of the planets and the stars. And the powerful light of truth frequently blazed up together with the terrible bonfires of the Inquisition in which the pathfinders of mankind were burned up. The gloomy forces of the Middle Ages, which were placed in the service of the authorities Ptolemy and Aristotle, stood in the path of sciences which was about to be developed. And only the genius of Copernicus and Galileo laid the foundation for the original investigation of space.

The investigations of the motion of the planets led first to the discovery of the descriptive laws of Kepler and then to Newton's significant law of attraction. Man began to find in his struggle with nature all the new sources of energy. Muscle power gave way to the energy of steam, electricity, and in our times, the gigantic energy of the split atom. Majestic prospects were opened up before mankind. Man fearlessly walked into the unknown, discovering on the Earth new continents, seas, and oceans, and discovering in the sky new planets, constellations, and nebulae, and penetrating always deeper into the secrets of the universe. And from the naive dreams wrapped up in legends, man, armed with the powerful knowledge of love of nature, came to the realization of the possibility of flight into space.

The problem of finding the means to accomplish this daring dream of mankind was placed before scientists and engineers. We now know why man has stuck so stubbornly, regardless of the difficulties and even sacrifices, to the penetration into space, and we have understood what role the study of outer space plays in the development of science and what practical possibilities have been opened before mankind in the utilization of outer space.

Our terrestrial ideas often prove to be completely inadequate for the correct understanding of the world around us. Processes occur in space which are huge by our standards of distance and time, beginning with thermonuclear reactions, which produce the energy of the stars, to the birth of new worlds. The discovery of radio galaxies, quasars, and pulsars, whose energy is liberated in the form of electromagnetic radiation, streams of relativistic particles, magnetic fields of great strength — all of this indicates that some kind of completely new transformations of matter and energy are taking place in the universe. One can say with assurance that the study of the state of matter under new physical conditions which appear, for example, in the case of the explosions of super nova stars and other features of the universe, exerts an enormous influence on the development of science and engineering. In space the physicists are encountering always newer laboratories of nature in which it is possible to observe processes still not reproducible on earth. The cores of some stars contain matter of a density a million times greater than the density encountered on the Earth, and the density of the gas in interplanetary space is a million times less than under the conditions of the best laboratory vacuum. Only in the depth of space are particles able to be created which possess an energy hundreds of millions of times larger than that which it is possible to obtain on a contemporary accelerator. /5

There appear in space with particular force complicated interactions of particles of matter with magnetic fields which have served as the basis for the development of a new area of physics, namely, cosmic magnetohydrodynamics. The combined motions of matter and a magnetic field, the motion in space of bunches of charged particles inseparably associated with the magnetic fields, "frozen into" a bunch, and special

magnetohydrodynamic waves all provide rich material for the understanding of the physics of space and open up broad prospects for their utilization in the creation of new sources of energy, such as plasma motors, with whose help further penetration into the depth of the universe will be possible.

Physicists have been studying cosmic rays for more than half a century, and they imagine them to be a flux of various particles of high and ultra-high energy. They carry enormous information about the microstructure and macrostructure of the universe. Actually, the pressure and energy density of cosmic rays (their energy per unit volume) in our stellar system are comparable with the pressure and energy density of the magnetic fields and with the density of kinetic energy of the moving interstellar gas. Therefore, cosmic rays play an important role in the study of the evolution of our Galaxy. The pressure of cosmic rays in radio galaxies is greater than the pressure and energy density of the magnetic fields, as a result of which there occur at a certain stage explosions in the radio galaxies with an enormous expulsion of gas and cosmic rays. All these are /6
phenomena of enormous scales and colossal energy. Moreover cosmic rays are a typical object of the microuniverse, since they consist of elementary particles (protons, electrons, γ-quanta) and the nuclei of various chemical elements accelerated to very high energies. The physics of high energies or, as it is called, the physics of elementary particles, owes its birth precisely to the cosmic rays.

The nature of the interaction of particles at ultra-high energies is of fundamental importance in the problem of the study of the history of the universe in connection with the discovery in the centers of galaxies of material which concentrates there an enormous energy supply in itself. The presence of two aspects

of the problem of cosmic rays has led to the appearance of two directions in the physics of cosmic rays, namely, the nuclear physics approach and the space physics approach. However, regardless of the fact that the role of cosmic rays in the study of deep phenomena of nature has only comparatively recently become clear to scientists, it has not been possible until the most recent times to use completely all the potential power of this method of research in various areas of science. The matter consists of the fact that the carrying out of corresponding experiments under terrestrial conditions requires very long time intervals sometimes computed to be years. This time is significantly shortened if the experiments are carried out either at high altitudes in the earth's atmosphere, or beyond the limits of the atmosphere with the application of heavy scientific equipment.

One of the most important problems of the study of space is the energetics of space processes. It should be emphasized that this problem, besides its own fundamental scientific value, has an enormous practical meaning. As A. B. Severnyy writes, "... contemporary space physics sets the problem of uncovering the essence of processes which result in the super-powerful liberation of energy in space objects, such as the Sun, the stars, the nuclei of the gigantic stellar systems, the galaxies ....

"For a long time it was not possible to solve the puzzles of the energetics of space, until the proposal was advanced that at the basis of the energy generation of stars lie thermonuclear reactions which should inevitably arise in the incandescent, essentially hydrogen mass of the star and maintain its heating at a constant level. Thus almost a quarter of a century ago the notion was developed that stars are gigantic self-supporting

thermonuclear reactors. The discovery of one of the secrets of outer space laid the foundation for the contemporary efforts of physicists for controlled thermonuclear reactions ... ."

Recently astronomers have discovered in distant regions of the universe a number of individual "beacons" which are glowing with fantastic brightness. They have named these objects quasi- /7
stellar objects, or quasars. The quasars indicate the possible presence in the universe of a new force so enormous that it is difficult to imagine it. Different points of view have been expressed on the nature of the quasars. It is certain without a doubt that this marvel of space ("the terrible X", as the physicists and astronomers speak of it) plays a revolutionary role in the understanding of many processes occurring in the universe and is similar to the discovery of thermonuclear reactions, and will exert a significant effect on the development of contemporary physics and the technical progress of human society.

The study of the planets and the celestial object nearest to us, the Moon, has enormous scientific and practical significance. The discovery of general regularities in the evolution of the planets of the solar system, their formation, and the study of the surface and atmosphere of the planets permits a deeper understanding of the nature of the Earth with the purpose of improving the life of its inhabitants.

There are many unclear questions in the problem of the origin of the planets. Moreover, only the development of space technology permits accumulating the necessary experimental data for the creation of a correct quantitative theory of the formation of the solar system.

One can divide the problem of the investigation of the Moon into essentially three categories:

a) the structure of the lunar interior and the processes taking place in the lunar interior;

b) the structure and composition of the lunar surface and their formation; and

c) the history and evolution as a result of which the contemporary lunar surface was formed.

The categories listed refer to all the objects of the solar system of planetary and subplanetary sizes. Concerning the Moon, the processes which refer not only to its surface but which are general for the solar system are of particular interest. In the first place, this aspect relates to the problem of the interaction of the solar wind with the planets and objects of the solar system.

In this connection it is exceedingly important to distinguish four main problems:

a) interaction of the solar plasma with planets having a magnetic field and an atmosphere (Earth, Jupiter);

b) interaction of the solar plasma with planets having an atmosphere but no magnetic field (Venus, Mars);

c) interaction of the solar plasma with celestial objects having neither an atmosphere nor a magnetic field (the Moon and other satellites of the planets); and

d) interaction of the solar plasma with comet tails. /8

The investigation of these effects is important for the study both of the celestial objects themselves and for their

immediate surroundings.

The study of the Moon is of particular significance, because the ancient rocks and deposits on its surface can serve as the basis for the chronology of events relating to the formation or accretion of the planets of the terrestrial group (Earth, Mars, Venus).

The main purpose in investigating the Moon is to study the past of our planet and the solar system. The principal moment in the temporal outlook is the discovery of a stratigraphic sequence of the order in which the deposits of the past were laid down. The difficulty of ground-based recording is caused by the fact that, as a result of active mountain building, erosion, and the effects of sedimentary rocks, any traces of the early period of the Earth's formation have been destroyed. At the present time we know almost nothing specific about the first billion years of the Earth's history.

The Moon is of particular interest for the investigation of the history of the solar system for two reasons. In the first place, the surface of the Moon may be one of several places at which the earliest stratographic evidence has been preserved and yields to interpretation. In the second place, because of the Moon's nearness to the Earth, a far more detailed study of the Moon's geology is possible than in the case of the geology of another near planet of the terrestrial group with the expenditure of the same effort. The events recorded on the Moon evidently have a larger degree of correlation with terrestrial events that do the events of history on other planets. From this point of view, the Moon's history should evidently resemble the Earth's history. The study of the Moon's origin permits clarifying finally the problem of the generality of the

evolutionary history of the Earth and the Moon. Since the geological processes which alter the surface of the Moon preferably act far more slowly than the geological processes on the Earth, part of the lunar stratographic evolution reflects the early history of the solar system, which could never be discovered on the Earth. The temporal variations preserved in the lunar layers refer to a number of processes of the solar system.

The solution of the problem of the origin of planetary objects will be significantly facilitated by the study of the primordial or very ancient surface of one of the objects of the solar system, the chemical and isotopic composition or even the intensity of old magnetic fields in the solar system by means of paleomagnetic measurements on ancient magmatic rocks. Many basic problems of the Earth can be solved by a comparison /9 of the Earth with the Moon. Up until the present time there was no complete clarity in the chemical evolution of the Earth's crust, which is complicated as a result of the transformation by surface water. The Moon can serve in this respect as an example of incomplete evolution. Possibly the Moon represents the best place for discussing how the early crust looks. The processes of mountain building on the Earth are understood only partially, since techtonically active regions are covered by oceans or thick sedimentary rocks.

As applied to the Moon, techtonic deformation of the surface can be studied without the masking effect of erosion and the formation of sedimentary rocks or oceans. In a similar fashion, volcanic products contaminated on the Earth by passage through chemically transformed surface deposits should be free from such effects on the Moon. The Moon is in second place after the Earth with respect to large objects of the solar system which can be studied directly by man. Besides the

satisfaction of natural interest in the composition and history of the Moon, its study makes it possible to understand the main problems of the morphology of the Earth and the planets of the solar system. Studies of the Moon's shape, the distribution of matter within it, the thermal flux from the Moon's interior, and the magnetic field broaden our knowledge of the composition and history of the Earth-Moon system.

If the Moon, as the nearest celestial object to the Earth, is of exceptional interest from the point of view of the history and evolution of the solar system and the study of the early stage of its formation, composition, and geological structure, the planets of the solar system have, along with the problems already discussed, the most important significance from the point of view of studying the formation of the hydrosphere and the atmosphere and the conditions under which the most powerful geological factor has arisen, namely, life processes.

In this respect, Mars is the most remarkable planet, having agitated for a long time the human imagination by the possibility of the existence there of life, perhaps in the most unexpected form. And if living organisms are actually discovered there, it will be possible to say without exaggeration that their study will become the problem of the century! The discovery of a new type of life will serve as the first biological connection of the Earth with other planets, and men of the Earth will be able to exert a significant effect on the subsequent development of extraterrestrial life and on the forms of its existence. However, the scientific complexities of the solution of this problem lie not so much in sending a spacecraft and setting up instruments on the surface of Mars, as in what signs we should use to establish the presence or absence of life on the planet. At the present time we still do not know a sufficiently reliable

method capable of singling out forms "on the side of life" from the absence of any signs of life. As William Corliss, who has discussed this problem, correctly points out "... what kind of questions should be asked in order to detect life? Of course, no one can give a 100% answer, but it is possible to distinguish the three major groups of problems: /10

a) problems associated with whether or not the planets being investigated have chemical compounds similar to amino acids and proteins;

b) problems associated with whether or not metabolism occurs and whether nutritive materials of the terrestrial type are absorbed by extraterrestrial samples in chemical reactions which are characteristic of terrestrial life; and

c) problems associated with whether or not forms of life (animals), the remains of living forms (fossils), or artificial structures ("canals") are discovered..."(1).

Not one of these questions is conclusive, since they are all based on the assumption that life on another planet is similar to terrestrial life. Nevertheless, we must still proceed precisely from this assumption, picking as our basis three separate signs of life: metabolism, replication, and evolution. These signs are universal for all living organisms on the Earth. From this point of view, the study of the physical conditions on the planets is an exceedingly important problem, since these conditions are suitable for biological processes to occur.

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(1) International Sciences and Technology, 1965, No. 37.

Mars is evidently the only possibility for discovering extra-terrestrial life within the limits of the solar system.

Concerning the problem of the search for extraterrestrial civilizations, we can repeat the words of the Greek philosopher Metrodor (4^{th} century B.C.) "... it seems absurd that only one stalk grows in a large field, and that there exists only one world in infinite space."

We will now relive the era of "great geographical discoveries" in space. "... first there were spices!" exclaimed S. Tsveyg in a narrative on the great journey of Magellan. What kind of "spices" can we expect in the investigation of space, and what practical use can mankind extract, creating unique spacecraft and spaceships and setting off in them on a journey "in the pursuit of light and space."

Many processes on the Earth require global scope, and the study of them is possible only with the help of methods which can be used to carry out simultaneously investigations over the entire terrestrial globe. Such investigations are important not only for the study of the atmosphere's upper /11
layers, but also in the study of global processes which take place in its lower layers and which are responsible for the changes in the weather. The use of satellites opened up enormous possibilities in the investigation of the energetics of the Earth as a planet, the thermal conditions of the terrestrial surface, the atmosphere, and a number of other problems.

Systems of meteorological satellites are one of the most important directions in the utilization of space rocket technology for practical purposes. The Meteor meteorological system has already been created in the Soviet Union and is

successfully operating. The meteorological information acquired is directly used for predictive purposes.

Other important directions are the use of satellites for deep space communication. It is known that the peculiarities of the propagation of radio waves do not permit establishing a direct radio link with all points of the terrestrial globe, particularly for direct television transmissions.

The most suitable communication satellites are those with high-apogee orbits. This situation permits not only increasing the transmission time, but providing a continuous connection between two points separated from one another by a significant distance. It is important to note that it is possible to set up a suitable link with the aid of a single satellite. For this purpose, it is necessary to choose correctly the altitude of the satellite's circular orbit and also to carry out the satellite's launch in such a way that the plane of the satellite's orbit coincides with the plane of the Earth's equator (equatorial orbit). If it is further required that the satellite's period of revolution be equal to the Earths' period of revolution of T = 24 hours, the altitude of its orbit should be equal to h = 36,454 km, as the calculations show. Such a satellite will "hang" motionless over a specified point of the Earth's surface. Satellites of this type are called synchronous, and their orbits are called stationary. In this case the maximum range of a continuous radio link amounts to $\sim$ 18,000 km.

If we create a system of three synchronous satellites arranged in orbit in a specified order, it is possible to carry out a continuous link over the entire terrestrial globe.

The Molniya system of satellites along with the Orbit system of ground-based stations has been created in the Soviet Union

and is operating successfully.

The application of satellites to agricultural purposes is one of the most important problems of contemporary space technology. This problem includes a combination of economic, social, and international problems. In effect the problem of the rational utilization of natural resources touches on the foundations of life on the Earth and includes:

1) the production of food products extracted both on land and in the ocean, from the point of view of the national and international food budget; /12

2) the management of forestry;

3) the use of water resources, including river basins, the waters of continents and coastal regions of the oceans;

4) the condition of nature, such as the problems of the contamination of water and air, noise and the maintenance of native natural resources;

5) the interaction of man and nature — organization, the creation of new cities, and the regeneration of natural resources; and

6) transport, in particular, navigation in the oceans.

For the present it is possible to speak in this sense of various tempting prospects. First of all, television and infrared images of the Earth are very interesting. Photography of natural features from spaceships is of particularly great interest.

High spatial resolving power of the images (not only color) photographs, but also pictures in various spectral regions) is of exceedingly important significance for the use of such photographs in the interests of a wide group of sciences of the Earth and also for geobotanical, agribiological, and other research. Photographs taken from space satisfy these requirements exactly best of all.

With all the achievements of contemporary automation and remote control, the brain of a man remains the most reliable programmable device from the point of view of rapid logical analysis of a situation and the adaptation of a solution for the course of an experiment. Therefore, the participation of man in accomplishing scientific programs onboard a satellite has such an important advantage as the intentional selection of the objects of investigation. Since an image of the terrestrial surface serves first of all as the main data, visual observations of a cosmonaut play a large role. It is true that a man is able to perceive the surrounding world with the help of the sense of vision in only a very narrow spectral region, which is called the visible region of the spectrum. As a rule, normal photographs refer to this region of the spectrum. However, the photographic film can significantly widen the region of spectral sensitivity in the necessary cases, including in the direction of the infrared region, i.e., longer wavelengths.

Certain of these problems are being solved in the Soviet Union in the case of the flight of artificial satellites of the Kosmos series and the manned Soyuz spaceships.

From knowledge of the deepest properties of the universe to the practical utilization of scientific laws for the needs of mankind — such is the impetuous journey of the application /13

of space-rocket technology. We are approaching a new culmination of our century when the technical possibilities of our contemporary times will be realized together with the greatest discoveries of science about the universe. The well-known American physicist Z. Weisskopf wrote concerning this amazing unity of science and technology: "... space technology, which can permit us to investigate the unknown regions of the solar system, now enjoys great support. The investigation of the unknown was always a significant component of human strivings in our contemporary civilization. But it should keep abreast, as has always been done, with another component just as significant — the explanation of the unknown in whatever form we have encountered it. At the start of the sixteenth century, when the era of science was beginning, Magellan completed the first trip around the world. But at this same period Copernicus published his work on the motion of the planets."(2)

The 1960's of our century brought fundamental scientific discoveries in the study of the Moon and the planets of the solar system along with the most important achievements of space technology.

MAGNETIC FIELDS OF THE MOON, VENUS AND MARS

The problem of whether other celestial objects of the solar system possess their own magnetic fields has enormous significance for the study of the internal structure of the planets and their cosmogonical history. From this point of view, the

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(2) Uspekhi fizicheskikh nauk, Vol. 86, No. 4, 1965, p. 603.

direct measurement of the magnetic fields of the Earth, Venus and Mars with the help of spacecraft was of principal significance. During 1959 - 1970 flights of Soviet and American spacecraft were carried out towards the Moon, Mars, and Venus.

On September 12, 1959, the second space rocket started from the Luna-2 station, which on September 14, 1959 became the first spacecraft to reach the surface of the Moon. On board the station was mounted a 3-component magnetometer with a measurement range of 700 gammas (γ) (1 $\gamma = 10^{-5}$ oersteds), whose resolving power in each channel amounted to $\sim$ 30 γ during the flight.

The first and principal conclusion which it was possible to draw upon analysis of the magnetometer readings during its operation in the portion of the flight which comprised several fractions of a lunar radius gave proof of the fact that, if the /14
Moon possesses a magnetic field, the Moon's effective magnetic moment must be less than 10^{-4} of the Earth's magnetic moment. At the same time it was possible to assume the presence on the Moon of a weak magnetic field arising due to the interaction of the lunar surface and the solar plasma with a frozen magnetic field and also due to residual magnetization. The solar wind is able to distort significantly the Moon's magnetic field and to "depress" it over the Moon's surface. In addition, the possibility was not excluded that the Earth's magnetic "circuit" stretching from the nighttime side of the lunar surface, also exerts an effect on the Moon's magnetic field. The measurements carried out by the American Explorer-18 satellite showed some increase of the magnetic field when the satellite was located at a distance of 150 lunar radii from the Moon's surface.

The proposal was advanced (Ness and others) that at the time the Explorer-18 satellite was located within the region of a shock wave formed upon the interaction of the solar wind with the Moon's surface, by which an insignificant increase of the magnetic field in the vicinity of the Moon is caused. Problems of the formation of a shock wave near the Moon were discussed in detail by Michel, Gold, and Tozer (USA).

A possible mechanism for the formation of a shock wave is associated with the compression of the lines of force of the magnetic field frozen into the plasma upon the flow around a celestial object having a high electrical conductivity. In this case two possibilities are realized: (1) the average conductivity of the celestial object is high, and the thickness δ of the skin layer is small in comparison with the object's radius, i.e., $\delta \ll R$; (2) a strongly conducting core is present at the center of the celestial object. In the first case the condition for the formation of a shock wave is : $\frac{8\pi\sigma_M R_M \cdot v}{c^2} \gg 1$, where σ_M is the Moon's conductivity.

The mechanism for the formation of a shock wave is associated with the fact that the lines of force cannot penetrate inside the celestial object, and at its surface is formed an induced magnetic field which does not permit the particles of the solar wind to recombine on the lunar surface. If one substitutes the necessary numerical values, we obtain for σ_M the value for which the formation of a shock wave is possible: $\sigma_M \gg 10^{-8}$ (ohms·cm)$^{-1}$.

In the second case the plasma of the solar wind is absorbed by the object's surface, and the lines of force of the plasma's magnetic field pass into the object's interior, being retained at the conducting core and forming an induced magnetosphere

within a layer with weak conductivity. In connection with this situation, it was necessary to solve the problem of the actual existence of a shock wave at the Moon.

At the end of March, 1966, the first artificial lunar satellite, /15 the Luna-10 spaceship was launched. The resolving power of the three-component magnetometer mounted on this spacecraft was $\sim 1\ \gamma$ for each component. The results of the measurements showed (both in the case in which the Moon was located within the Earth's magnetic tail and outside of it) that the Moon does not have its own field of a dipole nature and also that the measured field is of a regular nature. A value for the field of $\sim 10 - 15\ \gamma$ was attained only for the transverse component $B_\perp$ of the magnetic field (Dolginov et al.).

In 1967 the American Explorer-35 satellite was placed into orbit around the Moon. At this time the American spacecraft Explorer-33 and Explorer-34 launched earlier were still operating in interplanetary space. The simultaneous measurements by three spacecraft confirmed the result of Luna-2 and Luna-10 that a shock wave is not formed at the Moon, the plasma of the solar wind is absorbed by the Moon's surface, and the magnetic lines of force pass freely through the body of the Moon. Thereupon it was shown that the fronts of the fluctuations of the magnetic field are not significantly distorted during the passage. Under these conditions it was possible to show that the Moon's average conductivity is $\sigma_{avg} \sim 10^{-8} - 10^{-7}$ $(\text{ohms} \cdot \text{cm})^{-1}$.

The experimental investigation of the magnetism of the planet Venus was begun in December of 1962 when the Mariner-2 spacecraft flew by at a distance of 41,000 km from the center of Venus. Measurements by Mariner-2 did not detect significant variations of the magnetic field which it would be possible to

associate with the presence of the planet.

In June - October of 1967 the prominent flight of the Venera-4 spacecraft to the planet Venus was carried out. Magnetic measurements by the Venera-4 station were carried out right up to distances of 200 km from the planet's surface. The magnetometer's range of field measurements amounted to $\pm$ 50 γ with respect to three components and the sensitivity was $\sim$ 1.6 γ. The Venera-4 station approached the planet from the nighttime side near the terminator line (the day-night boundary) and the equator. From distances of $\sim$ 38,000 to 6300 km to the center of Venus, the data on the magnetic field measurement were taken every seven seconds.

The nature of the variation of the magnetic field during the portion of the flight prior to encounter can be presented in the following manner: at a distance of $\sim$ 38,000 km (the moment the measurements started) the field amounts to $\sim$ 18 γ, which significantly exceeds the value of the interplanetary field on magnetically quiet days. At a distance of 28,000 km from the center of Venus the magnetic field intensity fell to $\sim$ 14 γ. The nature of the field along the preplanatary portion 38,000 - 28,000 km was regular, and the field itself varied little in direction. Along the portion of the flight between /16
28,000 and 6300 km the nature of the field varied sharply: two maxima were noted in the field intensity, mainly, 32 γ at a distance of 23,000 km and $\sim$ 30 γ at a distance of $\sim$ 15,000 km, the field being strongly turbulent. Along the final measurement section, i.e., at a distance of 6300 km, the value of the field was equal to $\sim$ 18 γ, the same as at a distance of 38,000 km.

A significant peculiarity of the appearance of maxima in the magnetic field intensity is the fact that they coincided

with a sharp increase in the plasma concentration. Analysis of the magnetic measurements along the preplanatary portion of the flight of the Venera-4 spacecraft has permitted establishing:

1. The planet Venus does not possess its own dipole magnetic field. The ratio of the Earth's dipole moment to that of Venus is equal to $M_E \sim 10^4 M_V$.

2. Upon the interaction of the solar plasma with the planet Venus a "shock" wave arises, i.e., the planet exerts a perturbing effect in the interplanetary medium.

The mechanism of formation of a shock wave at the planet Venus upon the flow around the planet's body by the plasma of the solar wind can be associated with two physical peculiarities (in the absence of the planet's own magnetic field):

Inside Venus there is a core with high conductivity. In this case, as approximate calculations have shown (K. I. Gringauz et al.), it is sufficient for the formation of a shock wave near the head-on point that the thickness of the conducting envelope be ten times smaller than the Earth's conducting envelope;

Venus possesses an ionosphere with high conductivity.

As the American measurements on the daytime side of Venus at an altitude of $\sim$ 140 km have shown, there is detected a main maximum of electron concentration with $N_e \sim (5 - 6) \cdot 10^5$ cm^{-3}. Therefore the second proposal is completely sufficient for the formation of a shock wave.

Calculations of the position of the shock wave front in the gasdynamic approximation were carried out for various Mach

numbers (M = 2 - 10) after the flights of the Venera-6 and Mariner-5 spacecraft (Gringauz, et al.). However some discrepancies were detected here with the times at which recording began of plasma disturbances and the calculated cross section of the shock wave front of the Venera-4, Venera-6, and Mariner-5 spacecraft. Evidently, this fact indicates that the relations of gas dynamics, on the basis of which the calculations were carried out, do not satisfy very well the data of the magnetic and plasma measurements near Venus and do not permit a definitive solution of the problem of whether or not there actually occur the mentioned disturbances of the shock wave. There is still no rigorous kinetic or magnetohydrodynamic theory of the interaction of the plasma of the solar wind with a celestial object which does not possess an intrinsic magnetic field but which has a conducting gaseous envelope, which significantly hinders the correct interpretation of the results of the measurements. In connection with this fact, model experiments under laboratory conditions take on particular significance (I. M. Podgornyy, et al.). /17

In July of 1965, the Mariner-4 spacecraft flew by at a distance of 13,200 km (3.9 Martian radii) from the center of Mars. Magnetic measurements were carried out with the help of two magnetometers: an iron-probe magnetometer with a resolving power of 0.35 γ in each of three components and a helium magnetometer for measuring the scalar magnitude of the field with an error of $\sim$ 0.1 γ.

On July 14, 1965 at 01^h23^m Universal Time the measured values of the field changed abruptly by 5 γ and the fluctuations intensified. Disturbances of the magnetic field continued for about three hours, after which the value of the field approached the interplanetary value. Evidently, the spacecraft crossed in

this case the boundary of the shock wave front. If one proceeds on the assumption that the position of the shock wave front follows the pattern of the position of the shock wave front at the Earth, one can estimate the magnetic moment of Mars from the relationship

$$M_M = M_E \left(\frac{R_M}{R_E}\right)^3 \cdot \left(\frac{P_M}{P_E}\right)^{1/2},$$

where M_M and M_E are the magnetic moments of Mars and the Earth, and P_M and P_E are the solar wind pressures at the boundary of the shock front of Mars and the Earth. Taking into account the measured values $P_M = 2 \times 10^{-8}$ dynes/cm^2 and $P_E = 0.5 \times 10^{-8}$ dynes/cm^2, we get $M_M << 10^{-4} \cdot M_E$ for an estimate of the magnetic moment of Mars (Smith, Davis).

THE ATMOSPHERES OF VENUS AND MARS

The investigation of the atmosphere of Venus by spacecraft was begun in 1962 when on December 14 the Mariner-2 spacecraft, flying past the planet, first carried out measurements of the temperature of the cloud cover and the surface of Venus. However these data were not able to give any bases for constructing a quantitative model for the atmosphere of Venus due to the absence of information on the chemical composition of the atmosphere.

The first fundamental measurements of the main parameters of the atmosphere of Venus were carried out in 1967 when on October 18 the Venera-4 spacecraft completed its smooth descent in the planet's atmosphere. Right behind the Venera-4 spacecraft, the Mariner-5 spacecraft flew by the planet Venus the following day at a distance of 3,970 km from the surface. This /18

spacecraft gave much valuable supplementary information and permitted refining in a number of cases data obtained by the Venera-4 spacecraft.

The transmission of scientific data during the descent of the Venera-4 spacecraft (its descent stage) lasted 23 minutes, right down to an altitude of 28 km above the surface of Venus. However, the possibility was not excluded (due to peculiarities of the operation of the radar altimeter with periodic modulation) that the altitude could have differed by approximately 30 km. Such a scatter in the tie-in of the scientific measurement data affected significantly the interpretation of some of the results obtained by the Venera-4 spacecraft.

In January of 1969 the Venera-5 and Venera-6 spacecraft started for the planet Venus. These spacecraft completed a smooth descent in the planet's atmosphere on May 16 and 17. The transmission of data from the descent stage of the Venera-5 spacecraft in the atmosphere of Venus lasted for 53 minutes, and it carried out measurements along a descent path of 36.7 km. The transmission of data from the descent stage of the Venera-6 spacecraft lasted for 51 minutes, and it carried out measurements along a descent path of 34.2 km.

Investigations of the planet Mars by spacecraft were begun in 1965. On July 15, 1965 the Mariner-4 spacecraft flew by at a minimum distance of $\sim$ 10,000 km from the surface of Mars. After flying by Mars the Mariner-4 spacecraft went into a heliocentric orbit around the Sun and communication with it was maintained for more than three years. The last radio communication session took place on December 20, 1967, when the spacecraft again approached the Earth to a distance of less than 50 million km. This circumstance permitted receiving part of the information

stored on board the spacecraft.

In 1969 the Mariner-6 and Mariner-7 spacecraft were launched towards Mars. On July 31 the Mariner-6 reached the vicinity of Mars and flw by Mars at a distance of 3,430 km, and on August 5, 1969 the Mariner-7 spacecraft flew past Mars.

The study of planetary atmospheres is a problem of enormous scientific significance with which is associated an understanding of many regularities in the origin of the planets themselves, the dynamical equilibrium of the energy arising from the Sun and reflected by the planet, and the possibility of life arising on this or the other planets.

In order to illustrate clearly the difficulties which arise upon the interpretation of data on planetary atmospheres, we will use a certain methodical procedure of the American meteorologist G. Ohring, who used it as a reply to the question: what is the chemical composition of the atmosphere of planet X if the following facts are known: /19

1) carbon dioxide gas is contained in the atmosphere of planet X, and this is the only gas which it has been possible to detect up until now;

2) the mass of the atmosphere of planet X is far greater than the mass of carbon dioxide gas contained in it;

3) about 80% of the Earth's atmosphere consists of nitrogen;

4) nitrogen is distributed in a sufficient amount in space: it is detected on such astronomical objects as the Sun and the stars;

5) it is practically impossible to determine directly whether or not there is nitrogen in the atmosphere of the planet X, since it is very difficult to detect nitrogen spectroscopically by observations from the Earth.

G. Ohring concludes that it is logical in such a situation to arrive at the conclusion that the planet X consists mainly of nitrogen and also a certain amount of carbon dioxide gas. This conclusion is strengthened by two circumstances. In the first place, by analogy with the terrestrial atmosphere if the planet X is a neighbor of the planet Earth; in the second place, on the basis of cosmic analogy, since nitrogen is contained in other celestial objects. Such a statement of the problem is very typical with respect to the planet Venus: it was assumed right up until direct measurements were carried out from the Venera-4 spacecraft that the main gaseous component of the atmosphere of Venus was nitrogen with an insignificant admixture ($\sim$ 10 %) of carbon dioxide gas and other components.

Measurements of the chemical composition of the atmosphere of Venus by the Venera-4, Venera-5, and Venera-6 spacecraft were carried out under the direction of Academician A. P. Vinogradov. It was assumed in the initial arrangement of the experiments that nitrogen (N_2) and oxygen (O_2) are contained in the atmosphere of Venus in sufficient amounts. On account of the contradictory nature of the data relative to CO_2, H_2O, O_2 and N_2 from the Venera-4 spacecraft threshold measurements were primarily carried out. The determination of the chemical composition was specified with the help of 11 gas analyzers; five analyzers operated at a pressure of 550 mm Hg and a temperature of $\pm$ 10° C, and the remaining six analyzers operated at a pressure of 1500 mm Hg and a temperature of 90 $\pm$ 10° C.

Measurements were carried out by the Venera-5 and Venera-6 spacecraft during the parachute descent portion of the flight, and the pressure and temperature varied from 0.6 atm and 25° C to 27 atm and 320° C.

Gas analyzers are hermetic cylindrical pressure detectors of the diaphragm type and permit determining as a function of their design the absolute pressure or the pressure difference which arises due to the absorption of the component being measured in one of the detector's chambers. Corresponding absorbers were selected for each of the components. Potassium hydroxide with /20
a lithium additive (3%) was used for carbon dioxide gas, with complete absorption occurring in a time of 35 - 40 seconds. In order to avoid the error associated with the absorption of water vapor by potassium hydroxide, $CaCl_2$ was placed in another compartment to absorb moisture.

The CO_2 content in Venus's atmosphere amounted to $\sim 90 \pm 10\%$ on the basis of the measurements by the Venera-4 spacecraft. The more accurate measurements by the Venera-5 and Venera-6 spacecraft significantly refined the carbon dioxide gas content and gave an average value of $\sim 97 \pm 4\%$. In order to determine the nitrogen content, a zirconium absorber was used at a temperature of 800° C. A quartz capillary tube with a tungsten filament inside it to heat it up was used to heat up the zirconium.

Since CO_2, H_2O and O_2 are absorbed simultaneously with nitrogen, for comparison potassium hydroxide was placed in the cell to absorb CO_2 and H_2O, and phosphorus was placed in the cell to absorb O_2. This method of determining the nitrogen content in the atmosphere was used by the Venera-4 spacecraft.

A more refined method was used by the Venera-5 and Venera-6 spacecraft. The nitrogen content was determined from the residual

pressure after the absorption of the main components (carbon dioxide gas, water vapor, and oxygen). As the measurements have shown, the nitrogen content in Venus' atmosphere is very low, namely, $N_2 \leq 2\%$.

The oxygen content was determined in two ways: by a manometric method and by a thermochemical method. As the absorber red phosphorus was used, which upon sublimation gives white phosphorus and absorbs oxygen well. This method was applied by the Venera-4 spacecraft. Since, on the basis of the results of the first measurements of Venus' atmosphere, it appeared to be very poor in oxygen, a thermochemical method was used on the Venera-5 and Venera-6 spacecraft to carry out threshold measurements: the interaction of oxygen with one of the refractory metals upon its being heated up. Tungsten (with the addition of a small amount of oxygen at a pressure of a few millimeters of mercury in order to avoid burning out the tungsten at high temperatures) was selected as the metal. As a result of the measurements it was shown that the oxygen content in Venus' atmosphere is $O_2 \leq 0.1\%$. The water vapor content was determined in two ways: by a manometric method (for a high moisture content) and by an electrolytic method (for a low moisture content).

In the first method the pressure difference was measured after absorption of the water vapor by calcium chloride in one of the cells, and in the second method the difference in the electrical conductivities was measured after absorption of the water vapor by P_2O_5. The measurement data showed the presence of water in Venus' atmosphere; as the pressure increases, the moisture content decreases. The water content at the condensation level was 11 mg/liter. /21

Thus it proved possible to obtain direct data for the first time in experimental astronomy on the chemical composition of Venus' atmosphere. The CO_2 content is 97 $\pm$ 4%, the O_2 content is no greater than 0.1%, and the N_2 content is no greater than 2%. On the basis of ground-based measurement data, CO, HCl and HF have been detected in Venus' atmosphere.

Measurements of the density, temperature, and pressure were carried out by the Venera-4 spacecraft with the help of a resistance thermometer, a densimeter using a β-source, and a manometer of the aneroid type. The measurement range of the densimeter was 5×10^{-4} - 1.5×10^{-2} g/cm^3. The measurement range of the aneroid-type manometer was 0.13 - 7.3 kg/cm^2.

Six pressure measurement devices and three temperature measurement devices were mounted on the Venera-5 and Venera-6 spacecraft. Manometers of the membrane type were used as the pressure detectors, resistance thermometers were used to measure the temperature, and a densimeter of the tuning fork type was used to measure the density.

The measurement ranges of the pressure detectors were as follows:

from 100 to 5,000 mm Hg
from 500 to 20,000 mm Hg
from 750 to 30,000 mm Hg.

To ensure reliability of the measurements the pressure detectors overlapped by pairs in each region. The measurement ranges of the resistance thermometers were as follows: 0 - 160° C, 142 - 370° C and 200 - 440° C. The measurement range of the tuning fork type densimeter was 0.5 - 40 kg/cm^3.

On October 18, 1967 at 7 hours 40 minutes measurements were begun in Venus' atmosphere of the thermal barometric parameters, and the measurements ceased at 9 hours 14 minutes. The density and pressure measurements were carried out until the instruments went off scale, which occurred at approximately 8 hours 52 minutes.

In connection with this situation it was necessary to extrapolate the density values which would correspond to the last temperature measurements. Several extrapolations were used: graphical extrapolations from the density-time and entropy-pressure diagrams (assuming a 100% CO_2 content). In this case the value $\rho_0 = 17.3 \cdot 10^{-3}$ g/cm^3 and $\rho_0 = 17.9 \cdot 10^{-3}$ g/cm^3.

Assuming that the hydrostatic equilibrium condition is valid in Venus' atmosphere and applying the ideal gas laws, it is possible to carry out an extrapolation using the following relation:

$$\left(\frac{\rho_2}{\rho_1}\right) = \left(\frac{T_2}{T_1}\right)^{\frac{n}{n-1}},$$

where n is the polytropic index, which is selected on the basis of its variation at the end of the measurement section. Another possibility for the extrapolation is the use of the barometric equation and the equation of motion of the descent stage in Venus' atmosphere. In these two cases the value $\rho_0 = 17.2 \cdot 10^{-3}$ g/cm^3 and $\rho_0 = 16.9 \cdot 10^{-3}$ g/cm^3 were obtained. As is evident, all the values obtained agree well with one another. The temperature along the measurement section varied in accordance with a quasi-linear law and had the value: $\sim$ 320° K - 530° K. Measurement of the values of the density and temperature make it possible to estimate the extent of the path covered by the descent stage in Venus' atmosphere.

/22

The distance covered by the descent stage in Venus' atmosphere can be determined by various methods: from the barometric equation, from the equation of motion of the descent stage with the ratio C_x/M computed for the stage in question (C_x is the aerodynamic drag coefficient and M is the descent stage's mass). It is very important to know whether or not the atmosphere is stable. The atmosphere's state is called stable if convective motions are absent in it. For an ideal gas the stability condition is the adiabatic law of temperature variation with altitude, i.e., $\Delta T/\Delta Z \leq g/C_p$, where C_p is the specific heat capacity at constant pressure, i.e., the vertical temperature gradient is less than the adiabatic gradient. Calculations have shown that the atmosphere is unstable along the descent path between 15 and 27 km, which is determined from the descent stage's equation of motion with $C_x/M = 0.00225$ kg^{-1}. If we proceed on the basis that the atmosphere is in a stable state along the descent path and is close to adiabatic, it is necessary to change somewhat the value of the coefficient C_x/M. With a value $C_x/M = 0.00176$ kg^{-1} the path traversed by the descent stage corresponds to a stable state of the atmosphere and is equal to $Z_{max} \sim = 28 \pm 1$ km. The descent stage's velocity varied from ~10 m/sec at the start of the descent path to 2 - 3 m/sec at the end of the section. Analysis of the atmosphere's stability was also carried out on the basis of the measured values of ρ and T independently of their altitude distribution, and it was shown that the atmosphere is in a state close to the adiabatic one along the descent section. An important method for checking the values of ρ, p, and T obtained is the Obukhov-Golitsyn's method of internal consistency which is based on an analysis of the dynamics of the spacecraft's descent in the planet's atmosphere if pairs of any of the three thermodynamic parameters associated with the equation of state are known. It is possible /23 to derive successively from the equation of hydrostatic equilibrium

and the descent stage's equation of motion the following three relations:

$$p_1 - p(t) = A \cdot \Phi_1 \{\rho(t), \rho(t_1)\}$$
$$\sqrt{p_1} - \sqrt{p(t)} = B \cdot \Phi_2 \{T^{-1/2}(t), T^{-1/2}(t_1)\}$$
$$\sqrt{p_1 T_1} - \sqrt{p \cdot T} = C \cdot \Phi_3 \{T^{-1/2}(t), T^{-1/2}(t_1)\},$$

where t_1 corresponds to the last measured value of the parameter, and the values of the constants A, B, C are determined from the following relations:

$$A = (2Mg^3/C_x S)^{1/2} = (3.31 \pm 0.02) \cdot 10^4 \ g^{1/2} cm^{1/2}/sec^3$$
$$B = (Mg^3 \cdot \mu/2C_x SR)^{1/2} = (0.733 \pm 0.003) \ deg^{1/2} \cdot atm^{1/2}/min$$
$$C = -\frac{\mu}{R}\left(\frac{Mg^3}{2C_x S}\right)^{1/2} = (8.75 \pm 0.12) \cdot 10^{-3} \ g^{1/2} deg/cm^{3/2} \cdot sec$$

The numerical values of A, B, and C were found by the method of least squares.

If one now plots for all three pairs of values their corresponding differences along the ordinate axis, starting from t_1, the last measurement time, and then the values of the measured parameter back in time to the time at which the measurements began, and if one plots the corresponding values of Φ_1 along the abscissa axis for the same instance of time, all the points will lie rigorously on a straight line which has a tangent of its inclination angle to the abscissa equal to the values A or B and C. This circumstance is proof of the internal consistency of the measured values of ρ, p and T with the numerical values found for A, B, and C. In addition, it is possible to express the value of the atmosphere's molecular weight in terms of the constants A, B, and C:

$$\mu = \frac{2RC}{A} \ ; \ \mu = \frac{RC^2}{B^2} \ ; \ \mu = \frac{4RB^2}{A^2}$$

where R is the gas constant.

We obtain for the values of A, B, and C found above the following:

$$\mu = \begin{cases} 44{,}0 \pm 0{,}9 \\ 44{,}2 \pm 1{,}5 \\ 43{,}7 \pm 09 \end{cases}$$

i.e., all the values agree well with one another, which indicates /24
that Venus' atmosphere consists essentially of CO_2.

Study of the thermodynamic parameters of Venus' atmosphere was continued by the descent stages of the Venera-5 and Venera-6 spacecraft. Both spacecraft entered the planet's atmosphere on the dark side approximately 2700 km from the terminator. The distance between the entry points of the spacecraft was about 300 km.

More reliable altitude measurements were carried out by the Venera-5 and Venera-6 spacecraft. The radar altimeter turned on by command the opening of the main parachute, and the measurements themselves were carried out by the method of frequency modulation. Within the altitude limits from 50 to 10 km, altitude readings were carried out by independent frequency filters. Calculations of the path covered by the descent stages in Venus' atmosphere as a function of time were carried out based on the equation of hydrostatic equilibrium, taking account of the equation of state of the gas (with the atmosphere's known composition $\mu = 42.3$ and the measured values of ρ and T) and on the basis of the equation of quasi-steady descent of the instrument by parachute (Avduyevskiy et al.).

$$gM \cdot \left(1 - \frac{\rho}{\rho_{ds}}\right) = C_x S \frac{\rho v^2}{2}; \quad z = \sum_{\tau_1}^{\tau_2} v \Delta\tau_i \quad ,$$

where $g \sim 8.8$ m/sec^2 is the gravitational acceleration on Venus, M is the mass of the descent stage, ρ_{ds} is the descent stage's average density, C_x is the aerodynamic drag coefficient, S is the cross sectional area, and z, v are the path traversed and the descent stage's velocity. It was assumed in the calculations that C_x is constant, and, in addition, $C_x/M = 1.7 \times 10^{-3}$ kg^{-1} was adopted.

The calculated velocity values had magnitudes from 32 to 6 m/sec for both descent stages. The distances calculated from the equation of hydrostatic equilibrium were compared with the readings of the radar altimeter at the corresponding instants of time. A comparison of all the data showed that the path traveled by the Venera-5 spacecraft from the time its parachute opened to the time it ceased transmission was equal to $\sim$ 36.7 km and was $\sim$ 34.2 km for Venera-6. Measurements of the parameters ρ and T by the Venera-5 probe began at 9 hours 02 minutes 30 seconds and stopped at 9 hours 54 minutes 56 seconds. The measurements made by the Venera-6 spacecraft started at 9 hours 08 minutes 15 seconds and finished at 9 hours 58 minutes 15 seconds. If one introduces into the discussion the average surface level of Venus as the average arithmetical value of the altitude measurements by the Venera-5 and Venera-6 spacecraft, it is possible to establish that measurements of ρ, p and T by both spacecraft stopped at an altitude of 20 km above the indicated level.

As has already been stated, on the day after the entry of /25
the Venera-4 spacecraft into the planet's atmosphere, the Mariner-5 spacecraft flew by it. The method of measuring the composition of Venus' atmosphere was based on the determination at various altitudes of the index of refraction in the 2297 MHz frequency region. The variations in frequency, phase, and

amplitude of the radio signal passing through various layers of the atmosphere upon the spacecraft's passing behind the planet's disk and upon its reemergence from behind it were recorded on the Earth.

As is well known, upon the passage of a radio signal through a planet's atmosphere the so-called critical refraction can occur i.e., in this case the radius of curvature of the radio wave becomes equal to the radius of the surface on which the index of refraction takes a constant value. A beam of radio waves propagating through the level of critical refraction and having rays which pass tangent to the critical level or below it is deflected in the direction of the planet. At this instant an interruption occurs in the reception of the radio signal at the Earth. Therefore, it is possible to determine from the radio occultation the refraction profile only down to the level of critical refraction. Radio refraction in an atmosphere consisting, for example, of a mixture (CO_2 - N_2) is determined by the equation

$$n=(134.9)\ \frac{P_{CO_2}}{T}+(80.29)\frac{P_{N_2}}{T}+(16.57)\left(1+\frac{5748}{T}\right)\frac{P_{H_2O}}{T}$$

where P is the partial pressure.

The equation

$$\frac{1}{R_c}=\frac{n-1}{n\cdot T}\left[\frac{g\mu}{R}+\frac{\Delta T}{\Delta r}\right],$$

where n is the index of refraction, serves as the condition of critical refraction in a spherically symmetric atmosphere.

Using the data on the chemical composition obtained by Venera-4, profiles of the refraction for Venus' lower atmosphere

were plotted with the help of the indicated relations. The transition from the measured refraction profile to the determination of the total concentration n* in the case of a known chemical composition for the lower part of the atmosphere is carried out according to the equation

$$n^* = \frac{n}{\Sigma \alpha_i n_i}$$

where n_i is the volume content of the i^{th} gas and α is an empirical constant ($\alpha_{CO_2} = 1.184 \cdot 10^{-17}$).

Furthermore, knowing the total concentration and the molecular weight, it is possible to determine with the help of the equation of hydrostatics the temperature at various levels. With the radius of Venus presently adopted, r_V = 6050 km, the last measurement data of Mariner-5 refer to an altitude 38 km above the planet's surface. /26

After the results obtained were compared with the value of the radius of Venus' surface (the Mariner-5 data were rigorously tied in to the planet's gravitational center), it became clear that the last measurements by the Venera-4 spacecraft refer not to the planet's surface, but to an altitude of 25 - 30 km above its surface, which evidently appeared as a result of an erroneous reading by the altimeter of the altitude 28 km at altitudes 50 - 60 km.

It is possible to connect the upper part of the derived refraction profile with the electron concentration by the equation

$$n = -40{,}3 \cdot 10^6 \frac{Ne}{f^2}$$

where f is the radio frequency in units of Hz.

Thus it proved to be possible to plot the distribution of electron concentration in Venus' daytime ionosphere.

Measurement of the water in Venus' atmosphere was carried out by the Venera-4, 5, and 6 spacecraft and turned out to be equal to 6 - 11 mg/liter (at a pressure of 2 - 0.6 atm). Calculation of the thickness of the cloud layer shows that it amounts to about 15 km. The clouds up to an altitude of $\sim$ 7 km above the condensation level evidently consist of water droplets, and higher up of ice crystals. The maximum water content of the cloud is $\sim$ 2.4 g/m^3 at a temperature of from -5 to -25° C and is located 5 - 10 km above the condensation level. The upper boundary of the clouds is diffuse. (A. P. Vinogradov, et al.)

The first direct data on the atmosphere of Mars were obtained in 1965 when the Mariner-4 spacecraft flew by the planet. Radio occultation of the spacecraft by the disk of Mars at a frequency of 2100 MHz was used as the method of measurement. The occultation of Mariner-4 lasted about an hour. The variations of the phase of the radio signals passing through the atmosphere of Mars were accurately recorded on the Earth during the spacecraft's setting and rising. The measurements during the setting and rising differed significantly from each other.

At the end of July and the beginning of August 1969, as we have already mentioned, the Mariner-6 and Mariner-7 spacecraft completed their flights past Mars. The spacecraft flew past Mars at an altitude of 3425 km. Observations were carried out both on the daytime and on the nighttime side of the planet, and broad spectroscopic and radio measurements were carried out. Spectroscopic measurements of the upper layers of Mars in the

ultraviolet region revealed carbon dioxide gas, carbon monoxide and small amounts of oxygen and hydrogen. These facts substantiate the hypothesis of the absence of life on Mars. The temperature of the planet's exosphere proved to be of the order of 400 - 500° K. /27

A sharp increase in the brightness of the polar cap was detected by Mariner-7 in the ultraviolet region. This fact has great significance, since it indicates that ultraviolet radiation evidently penetrates to the surface of Mars and that a medium (dust, clouds) which could absorb the radiation is absent.

Spectrometric measurements in the infrared region have also shown the presence in Mars' atmosphere of carbon dioxide gas, which is evidently the main gaseous component. In addition the spectra of solid carbon dioxide and water vapor, which appears in the form of an icy fog, have been detected.

Measurements of the temperature of the surface of Mars in the infrared region have shown that it can reach a value of 24° C in the daytime on the equator. The surface temperature from day to night experiences differentials from 15 - 20° C at noon to -100° C at night. The minimum temperatuee of the southern polar cap is $\sim$ 150° K. From this fact it is possible to make the proposal that the Martian polar caps consist of frozen carbon dioxide, since for the pressure range 2 - 9.5 mbar the freezing temperature of CO_2 varies within the limits of 140 - 150° K.

The radio occultation method was also applied by the Mariner-6 and 7 spacecraft. Reception of the radio signals was carried out simultaneously by 63-meter antennas in Australia and in the U.S.A. (California and West Virginia). The experiment was carried out at a wavelength of 12.5 cm with coherent radio

relaying from Earth and a relative stability of the ground-base transmitter of 10^{-12}. The results of the measurements were interpreted on the assumption of a spherically symmetric atmosphere of the planet. Data on the temperature and pressure were derived for the lower part of Mars' atmosphere on the basis of the obtained refraction profile, assuming that the atmosphere consists entirely of carbon dioxide gas. The value $r = 3393 \pm 6$ km for the equatorial radius of Mars was specified. The value of the atmospheric pressure at the surface of Mars was derived from this data to lie within the limits of 3.5 - 9 mbar with an average value of 6.5 mbar. The temperature at the surface reaches a value of $\sim 260°$ K. The derived values agree sufficiently well with the data obtained earlier by Mariner-4.

IONOSPHERE OF VENUS AND MARS /28

The study of the ionospheres of the planets of the solar system is of fundamental importance not only for an understanding of the origin of the atmospheres of the planets as a whole, but is also important from the point of view of providing reliable radio communication with spacecraft completing flights to the planets. The flights to the planets Mars and Venus by the Mariner-5, 6, and 7 and the Venera-4, 5 and 6 spacecraft provided an enormous amount of data for the study of planetary ionospheres and the comparison of them with the terrestrial ionospheres. Two methods have been utilized in the study of the ionospheres of the planets: radio occultation and recording of the ion composition with the help of plasma probes. On the basis of the data from the radio occultations of the Mariner-4 spacecraft by the planet Mars, the distribution of the electron concentration was obtained in the daytime and nighttime ionosphere. It turned out that:

1. The maximum electron concentration in the daytime ionosphere of Mars at intermediate latitudes is at an altitude of 125 km and is equal to $N_e \sim 9 \cdot 10^4 - 10^5$ cm^{-3}.

2. The altitude scale of the electrons above the maximum can be assumed to be approximately constant and equal to 20 - 25 km.

3. A small secondary maximum is observed at an altitude of about 20-25 km below the main maximum.

4. The electron concentration in the nighttime ionosphere of Mars does not exceed 10^4 cm^{-3}.

These results have been obtained by the single-frequency method. Due to the specific properties of the measurements themselves in the atmosphere's lower part, it is not possible in this case to distinguish uniquely between the contributions made to the value of the index of refraction by neutral and charged particles. Therefore, the electron concentration profiles of the ionosphere of Mars which were derived in the present experiment should be considered as an average picture. It is possible that local measurements will differ from the plotted profiles. The electron concentration profiles plotted on the basis of the Mariner-6 and -7 radio measurements have recorded a maximum electron concentration in the Martian ionosphere of $N_e \sim 1.5 \cdot 10^5$ cm^{-3} at an altitude of 130 km, which exceeds by 50% the value of the maximum obtained by Mariner -4. Evidently in the present case different periods of solar activity have appeared. The plasma temperature of the ionosphere at altitudes of 130-190 km turned out to be 400-500° K.

An investigation of the ionosphere of Venus was carried out by the Mariner-5 spacecraft and by the Venera-series spacecraft. A study of the ion composition was accomplished by the Venera spacecraft with the help of two-dimensional and hemispherical 3-electrode charged particle traps. Due to the fact that the range of the quantities being measured was significantly overestimated, it was possible to obtain only upper limits to the ion concentration in the nighttime ionosphere of Venus, which nowhere exceeded $\sim 5 \cdot 10^4$ cm^{-3}. Measurements of the low concentrations made it possible to establish an upper limit of $\sim 10^3$ cm^{-3} at altitudes above 300 km. The profiles obtained for the electron concentration by the radio ocultation method revealed the following structure of the ionosphere: on the daytime side there is a maximum concentration of $\sim 5\text{-}6 \cdot 10^5$ cm^{-3} at an altitude of about 140 km, and there is also an additional maximum at an altitude of $\sim$ 15 km below the main maximum. If we assume the main gaseous component to be CO_2 gas, the scale height above the main maximum amounts to $\sim$ 13 km, which corresponds to $T \approx 300^\circ$ K, and then an increase in the scale height is noticed as the altitude increases. /29

MODELS OF THE ATMOSPHERES OF VENUS AND MARS

Prior to the flights of spacecraft to the planets Mars and Venus, models of the atmospheres of these planets were constructed by various authors; however, they were all based on purely hypothetical assumptions as to the chemical compostion of the atmospheres and their structural parameters. Direct measurements of the main components of the atmospheres of Mars and Venus and also of the temperature and pressure have permitted for the first time the quantitative calculation of a number of new atmospheric models. At the present time the main component is taken to be

CO_2 gas in all the models both for Mars and Venus.

After the flight of the Mariner-4 spacecraft Chamberlain (England) and Kliore (USA) proposed a model of the upper atmosphere of Mars with an E region (E is a region in which the atmosphere is ionized by solar x-rays).

The temperature distribution and the electron concentration profile according to Chamberlain are presented in Figure 1.

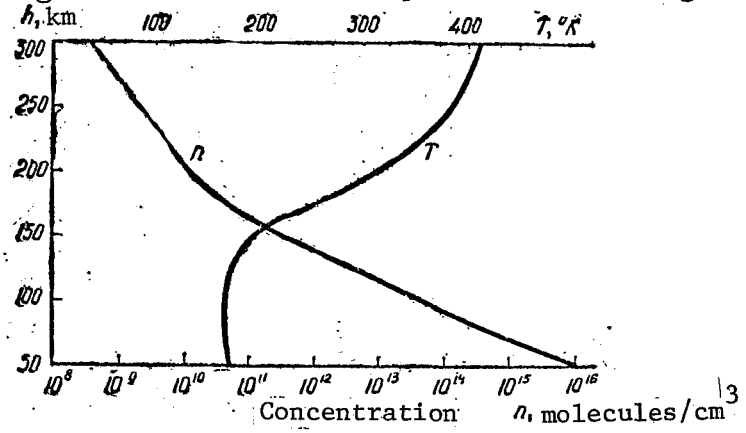

Figure 1. Model of the upper atmosphere of Mars.

It has been assumed in the plotting of the profiles that the dissociation of CO_2 is neglibly small and complete mixing occurs, the electron temperature of the exosphere being $T = 410^\circ$ K. According to Chamberlain's model, there are no F_1 and F_2, ionization regions in the thermosphere (a region in which the temperature increases with altitude). This feature agrees with the preliminary analysis of the Mariner-4 radio ocultation data (Kliore et al.).

In Johnson's model the temperature of the surface of Mars is taken $\sim 210^\circ$K, and the pressure $\sim$ 8 millibars. The main ionization maximum is analogous to the F_2 layer in the Earth's ionosphere, and the main ion at the maximum and above it is O+. The

temperature distribution according Johnson's model is given in Figure 2. The temperature distribution corresponds to a 3-layer structure of the model (troposphere, stratosphere, and isothermal thermosphere). Johnson's model was subjected to criticism by Chamberlain, who pointed out that the presence of an F_2 layer, the preponderence of the O+ ion, and the low temperature of the isothermal thermosphere are not consistent with the Mariner-4 data. /31

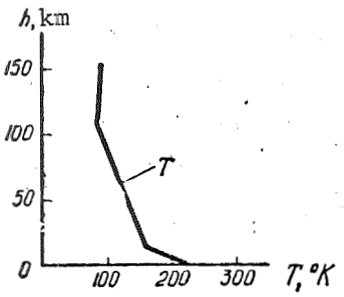

Figure 2. Temperature of the lower atmosphere of Mars.

A completely different temperature distribution is derived in the model of Gross, McGovern, and Rasool (Figure 3), on the basis of which the surface temperature as set at $\sim 200^{\circ}K$ and the surface pressure at $\sim$ 8 millibars. The lower atmosphere is in radiative equilibrium up to an altitude of 80 km with effective dissociation of the CO_2 gas. In contrast to Johnson's model, the temperature of the exosphere is $550 \pm 150^{\circ}K$, and there is a temperature maximum, namely, the mesopause, at an altitude of 80 km. Chamberlain has pointed out that, if ionization of oxygen atoms occurs due to far ultra-violet radiation, the maximum of the F_2 ionization should be located above 125 km, which is not consistent with Mariner-4 data.

McElroy proposed an interesting model of the atmosphere of Mars which consists of pure CO_2 gas in thermo-dynamic equilibrium. McElroy assumed that the surface pressure is equal to $\sim$ 6.3 millibars

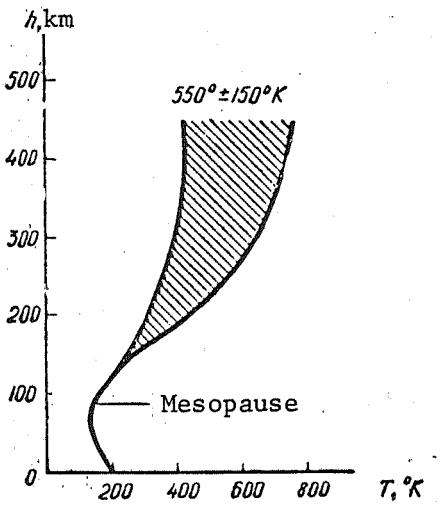

Figure 3. Temperature of the upper atmosphere of Mars.

and the surface temperature is $\sim 160^{\circ}$K. He took into account the fact that solar radiation is absorbed in the near infra-red and ultra-violet regions of the spectrum, and a redistribution of the radiation occurs due to the molecular thermal conductivity and radiative transfer in the $\lambda = 15$ micron band of CO_2 gas. /32

The temperature gradient up to an altitude of ~ 50 km is less than 1°/km. Further on, the temperature increases, and the transition to the exosphere begins at an altitude of 200 km with a temperature of $T = 487^{\circ}$K. The temperature distribution and the electron concentration distribution are shown in Figure 4. As McElroy himself points out, his model cannot explain well enough the experimental maximum of the ionization in the Martian atmosphere.

The Soviet astrophysicist V. I. Moroz constructed three models of the Martian atmosphere: a minimum model, an average model and a maximum model. The initial values presented in Table 1 were taken as the input data for the construction of the models.

These conditions were selected so that at any level (based on altitude) the maximum and minimum models give a maximum and minimum mass density. Furthermore it is assumed that the lower part of the atmosphere is completely mixed, the temperature distribution is determined by radiative equilibrium in the CO_2 bands, and the dissociation level of CO_2 corresponds to the photochemical /33

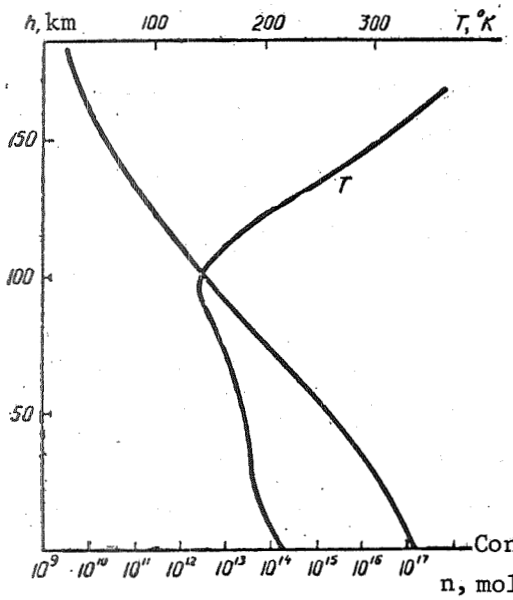

Figure 4. Model of an atmosphere of Mars consisting of pure carbon dioxide gas (CO_2).

equilibrium level which is located above the vibrational relaxation level of the $\lambda = 15$ micron CO_2 band. The temperature in the Earth's upper atmosphere is determined by a balance between a flux of ultraviolet radiation and the flux of heat arising because of absorbed energy, which is carried off below by the thermal conductivity. One more process played an important role in the thermal balance of the Martian atmosphere: the radiation in the

TABLE 1

Physical parameters	Max. model	Avg. model	Min. model
Surface pressure, mg	20	10	5
Chem. composition	10% CO_2 90% N_2	50% CO_2 25% N_2 25% Ar	100% CO_2
Effective surface temp. °K	270	250	225
Avg. molecular weight below CO_2 dissociation level	29.6	39	44
Avg. molecular weight above dissociation level	26	27	22
Temp. gradient above dissociation level 1°/km	1	2	0

molecular bands of CO_2. It is assumed in conection with this fact that the temperature at the photochemical equilibrium level is determined by the condition of the equality of the absorbed ultra-violet radiation energy and the energy radiated in the CO_2 bands.

The following parameters were calculated as functions of the altitude of all three models: temperature, pressure, number concentration, density, and the local pressure scale height. Temperature and density distributions corresponding to the three models are presented in Figure 5.

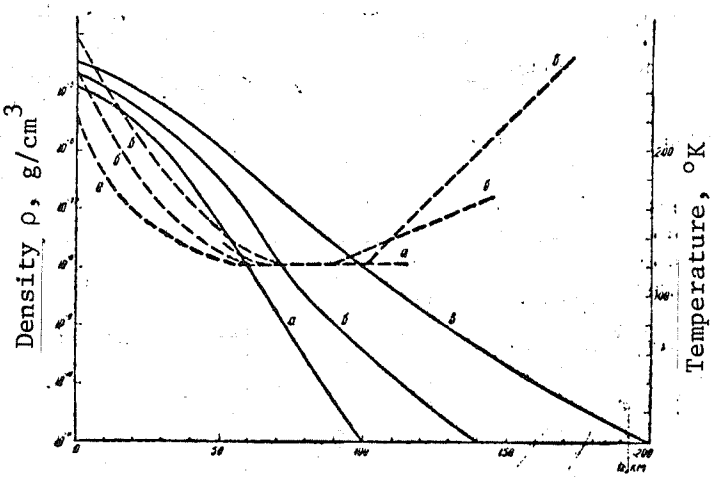

Figure 5. Models of the atmosphere of Mars:

a) minimum
b) average
c) maximum

_____ density

---------- temperature

In the models of V. I. Moroz conductive processes occurred in a lower layer with a thickness of 5-7 km in which the temperature gradient is adiabatic. Emmanuel calculated a convection zone on the lower atmosphere of Mars for different latitudes (equator, 30°, 60°, and the pole). The height of the convection zone increases as the latitude decreases. It rises above 10 km only at the equator. The temperature turns out to be the same ($\sim$ 163° K) for all latitudes at an altitude of $\sim$ 60 km.

All the models discussed are still unable to give a unique answer to the question of which type of ionospheric layers, D, E or F_1, F_2 (by analogy with the terrestrial layers), it is possible to assign the ionospheric layer in the atmosphere of Mars (Figure 6). This difficulty is associated first of all with /34 the absence of data on the neutral composition of the atmosphere in the region of the ionospheric altitudes. Therefore it is necessary to construct a model of the neutral atmosphere for various assumptions describing the electron concentration distribution which is derived. If, for example, we assume that photochemical equilibrium occurs in the atmosphere, the electron distribution can be described by models of the type of the terrestrial D, E or F_1 layers. If we assume that due to the highly rarified nature of the atmosphere at ionospheric altitudes /35 diffusion of molecules becomes a significant process, atmospheric oxygen should become the main component above some level, since it is significantly lighter than CO_2, CO, and N_2O_2. In this case the maximum ionization in the ionosphere of Mars can be assumed to be similar to the F_2 layer. It is thus evident that the final choice of a model of Mars presents well-known difficulties.

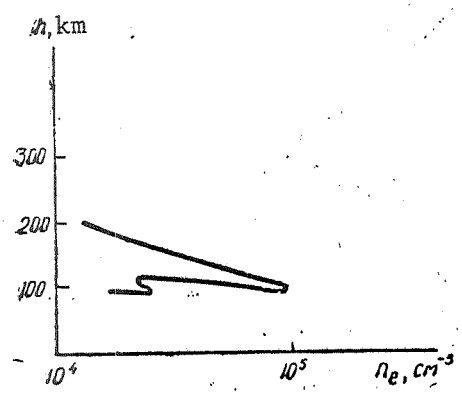

Figure 6. Distribution of the electron conentration (n_e) in the atmosphere of Mars.

Direct measurements in the upper atmosphere of the planet Venus have not detected a significant concentration of oxygen atoms. This fact permits us to assume that a maximum of the ionization is similar to the formation of the terrestrial F_1 or F_2

layers with CO_2^+ being the main ion.

On the basis of the reactions: $CO_2 + h\nu \rightarrow CO_2^+ + e$

$CO_2^+ + e \rightarrow CO + O$

with a reaction rate constant $K = 3.8 \cdot 10^{-7}$ cm^3/sec, McLeroy constructed an electron concentration distribution for the daytime ionosphere (Figure 7) which differs from the experimental distribution (based on Mariner-5) by less than 30%.

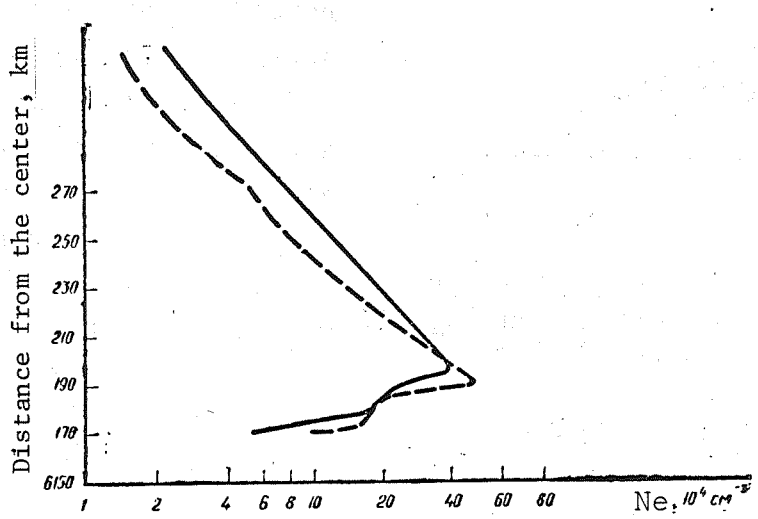

Figure 7. Model of the ionosphere of Venus:
---------- based on Mariner-5 data
———————— calculated

The agreement obtained between the theoretical and the experimental data indicates that the F_1 layer model evidently gives /36 a good description of the ionospheric maximum of the planet Venus.

Construction of quantitative models of the atmosphere of Venus on the basis of the Mariner-5 and Venera-4 data was carried out by the American scientists Kliore et al., McElroy, and C. Sagan and by the Soviet scientists V. I. Moroz, V. V. Mikhnevich, and by V. S. Avduyevskiy et al.

The simplest model of the atmosphere of Venus is McElroy's model, which consist of 100% CO_2. McElroy derived the distributions of the temperatures T and the electron concentration n for such a model, which are illustrated in Figure 8. Later on McElroy considered in detail a whole series of models (See Table 2).

The temperature and electron concentration distributions /37 for models E and D are presented Figure 9.

On August 17,1970 the Soviet Venera spacecraft was launched in the direction of the planet Venus. On December 15, 1970 the spacecraft completed a smooth landing on the planets' surface. During the spacecrafts' decent in the atmosphere of Venus, it suceeded in carrying out measurements of the temperatures right down to the very surface and on the surface itself.

The values of the atmospheric parameters at the planet's surface at the landing site of the descent stage are as follows:

temperature: $748 \pm 20^{\circ}K$,
pressure: 90 ± 15 atm.

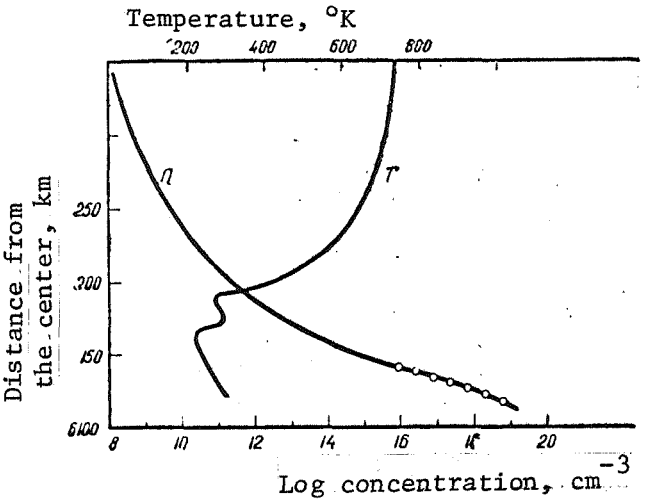

Figure 8. Model of the upper atmosphere of Venus: O - based on Mariner-5 data.

TABLE 2

Model	Composition of lower atmosphere	Level of sep. by diffusion, km	Composition at sep. by diffusion level
A	75% CO_2, 25% N_2	∞	—
B	75% CO_2, 25% N_2	6195	75% CO_2, 25% N_2
C	90% CO_2, 10% N_2	6190	90% CO_2, 10% N_2
D	100% CO_2	6185	80% CO_2, 10% CO 10% O
E	100% CO_2	6185	95% CO_2, 25% CO 5% O

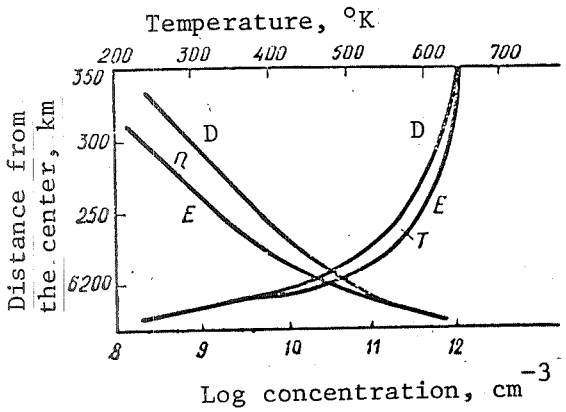

Figure 9. Models of the atmosphere of Venus (E and D) with separation by diffusion above 6185 km.

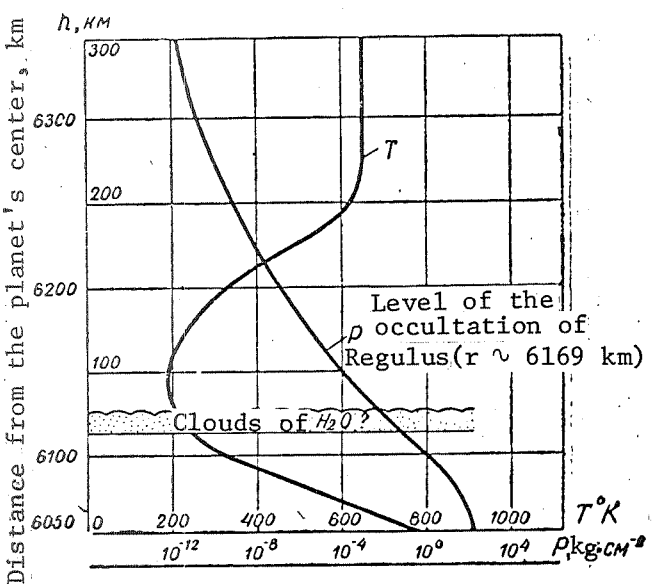

Figure 10. Refined model of Venus.

The collection of data obtained by the Venera-4, 5, 6, and 7 and Mariner-5 spacecraft, taking into account also ground-based data, have permitted the construction of a refined model for the pressure (P) and temperature (T) distributions in the atmosphere of Venus (Avduyevskiy et al.). This model is presented in Figure 10.

According to this model the temperature drops from 750 ± 20° K at the surface to 190° K at an altitude of 105 km, which is where the mesopause is located. The thermosphere of Venus (the region of a positive variation of the temperature gradient) for the conditions of average solar activity has a temperature of 650 - 700° K. The cloud layer, which presumably consists of ice crystals of approximately micron size, is located at the 60 - 70 km altitude region. /38

At the present time the Soviet astrophysicist V. I. Moroz has proposed a model

containing a distribution of the temperature (T), the pressure (P), the density (ρ), the concentration (n), and the chemical composition (μ) in the atmosphere of Venus.

The pressure and temperature relations T(h) and P(h) which were derived from the direct measurements by the Venera-5 and Venera-6 spacecraft, are extrapolated to the lower part of the atmosphere along an adiabat and to the upper part according to McElroy's model. V. I. Moroz adopts the following as the main components of the atmosphere of Venus: 90% CO_2 and 10% N_2 (the molecular weight is $\mu = 42.4$). The following values are adopted at the level of diffusive separation (h = 140 km): 90% CO_2, 10% N_2, 0.02% He, $1.2 \cdot 10^{-4}$ % D, and $8 \cdot 10^{-6}$% H.

The model constructed by V. I. Moroz from the planet's surface to an altitude of 6,000 km is presented by us up to the level of the upper boundary of the cloud cover (Table 3).

The working model of V. I. Moroz agrees well with the experimental data obtained.

INVESTIGATION OF THE SURFACE OF THE MOON AND THE MECHANICAL PROPERTIES OF ITS SOIL

Space flights to the Moon were begun in January of 1959 when the first lunar rocket Luna-1 was launched. The Luna-1 spacecraft flew by the Moon at a distance of about 6000 km from its surface. After flying past the Moon, the spacecraft went into orbit as a satellite of the Sun and became the first artificial planet of the solar system. In September of 1959 there was a new launch towards the Moon, and the Luna-2 spacecraft reached the Moon's surface. In October of 1959 the Luna-3 spacecraft conpleted its historic flight around the Moon, as a /40

TABLE 3. WORKING MODEL OF THE ATMOSPHERE OF VENUS (V. I. Moroz). *

Alt.	Temp.	Density	Pressure	Concentration	Av. mol. weight	Comments
h,km	T, °K	ρ, g/cm^3	P, atm	n, cm^{-3}	μ/cm^{-3}	
0	750	$6{,}3 \cdot 10^{-2}$	93,0	$8{,}8 \cdot 10^{20}$	42,4	Surface
5	713	5,0	69,0	7,0	42,4	
10	675	3,8	50.3	5,4	42,4	
15	636	2,8	35,0	4,0	42,4	
20	596	2,18	25,2	3,07	42,4	End of operation of the
25	556	1,58	17,3	2,23	42,4	Venera-5 and Venera-6
30	515	1,15	11,5	1,62	42,4	
35	472	$8{,}10 \cdot 10^{-3}$	7,40	1,14	42,4	
40	428	5,50	4,50	$7{,}74 \cdot 10^{15}$	42,4	
45	382	3,58	2,60	5,05	42,4	
50	340	2,16	1,43	3,04	42,4	
55	304	1,25	0,71	1,70	42,4	Start of operation of the Venera-4, Venera-5 and Venera-6
60	274	$6{,}6 \cdot 10^{-4}$	0,34	$9{,}0 \cdot 10^{18}$	42,4	
65	250	2,7	0,14	3,6	42.4	Upper boundary of the cloud layer
70	240	1,2	$5{,}5 \cdot 10^{-2}$	1,6	42.4	
80	220	$1{,}7 \cdot 10^{-5}$	$7{,}0 \cdot 10^{-3}$	$2{,}3 \cdot 10^{17}$	42,4	
90	200	$1{,}9 \cdot 10^{-6}$	$7{,}4 \cdot 10^{-4}$	$2{,}6 \cdot 10^{16}$	42.4	
100	180	$1{,}8 \cdot 10^{-7}$	$6{,}2 \cdot 10^{-5}$	$2{,}5 \cdot 10^{15}$	42,4	

*Translator's Note: Commas represent decimal points.

result of which photographs of the far side of the Moon's surface, which is invisible from the Earth, were transmitted for the first time to the Earth by a photographic television method. In July of 1965 a space rocket with the Zond-3 spacecraft was launched. The spacecraft's photographic television device was used to photograph the Moon's surface, and in particular that part of its invisible side which was not photographed earlier with the help of the Luna-3 spacecraft.

During this period of time flights to the Moon with a hard landing of the spacecraft on its surface were carried out by the American Ranger program. Photography of the Moon's surface was completed during the approach of the spacecraft to the Moon.

In 1966 a new phase began in the study of the Moon by spacecraft, namely, the accomplishment of a soft landing on its surface by spacecraft and the creation of artificial satellites of the Moon.

In February and December of 1966 the Luna-9 and Luna-13 spacecraft carried out a soft landing on the lunar surface in the region of the Ocean of Storms. Lunar panoramic photographs were transmitted to the Earth from these spacecraft. These photographs permitted obtaining for the first time data on the microstructure of the lunar soil and the study of the morphological peculiarities of the lunar surface. In addition the Luna-13 spacecraft carried out direct measurements of the physical-mechanical properties of the lunar soil with the help of a number of devices (soil meter, dynamograph, and a radiation densimeter).

The Luna-10 spacecraft became the first artificial satellite of the Moon in April of 1966. The Luna-11, 12, and 14 spacecraft which followed it permitted solving a number of the main problems in the structure of the Moon, the composition of its rocks, and the surface properties of the lunar soil. In 1968 - 1969 spacecraft of the Zond series carried out flights around the Moon and returned the results of their scientific investigations to the Earth.

During 1966 - 1968 seven American Surveyor spacecraft were launched. Five of them carried out a soft landing on the Moon's surface. The spacecraft landings were carried out in various

regions which were of important significance for obtaining data on the properties of the lunar rocks. At this time five American Lunar Orbiter spacecraft were placed into selenocentric orbit, and they transmitted a significant number of photographs of the lunar surface to the Earth.

The flights of the American astronauts to the Moon and the return of the first samples of lunar soil to the Earth for study were tremendous events in the history of mankind.

On July 21, 1969 at 5 hours 56 minutes* a man from the Earth, /41
the American astronaut Neil Armstrong, first set foot on the Moon's surface in the region of the Sea of Tranquility. Neil Armstrong was joined 15 minutes later by Edwin Aldrin. The emergence of the astronauts from the lunar module and their first steps on the Moon were broadcast over television.

The age of space research is a continuous pursuit of the amazing. In order to cover the journey from the first flights of spacecraft to the Moon up to the first small step of a man from the Earth on the Moon, but a giant leap for all mankind, an unusual creative effort was necessary, which resulted in the creation of the most powerful rocket motors, the rocket itself, unique control systems, an orientation system, life support systems, and automatic systems for the return of the spaceship to the Earth. A heroic Odyssey was necessary in working out all the elements of the spaceship in orbits around the Earth and the Moon. If all this effort is measured on a scale of time of only a few years in all, it is easy to imagine the technological potential mankind possesses for accomplishing his most daring projects.

*Moscow time. T.P.R.

However, the Amazing lies not only in what man discovers but also in what means he uses. The engineering and design concept in each space experiment seeks an optimal solution of a problem, introducing into the first design the solution of the primary question: man or automatic machine. Safety, economy, reliability, and efficiency are the main scientific -engineering criteria in the creation of any space device.

It is now already possible to express the idea of whether or not flights of manned spaceships for a long period of time are inferior in economy, reliability, and efficiency to automatic spacecraft for lengthy flights to enormous distances. The fact that it is impossible to create a manned spaceship weighing only a few hundred kilograms indicates eloquently that flights to the planets will continue exclusively by means of automatic spacecraft. Undoubtedly, the creation and flights of manned spaceships in near-Earth or even lunar orbits will play an enormous role in the solution of many scientific and national economic problems. At the same time the statistics themselves of space flights already proved persuasively which methods are best suited to use for the investigation of space. Approximately 20 - 30 automatic spacecraft are necessary per each manned flight. This ratio is the same for the two most powerful space powers, namely, the USSR and the USA. The role of space automats in the study of celestial objects of the solar system was splendidly proven by the flight of the Luna-16 spacecraft, a new type of automatic spacecraft, which discovered essentially new methods for the investigation of space. /42

The Luna-16 spacecraft was launched on September 12, 1970. After flying in an intermediate orbit as an artificial Earth satellite the engine of the next stage was fired 70 minutes after launch, and the spacecraft began its flight along a

trajectory to the Moon. All the operations which the spacecraft had to carry out during its flight to the Moon, at the moment of the landing on the lunar surface, the operation of the drilling mechanism, the sampling of the lunar soil, and, finally, the launch from the Moon, all these were stored in the spacecraft's logical system right here on the Earth, and they were controlled by command from the Earth.

During the flight of the Luna-16 spacecraft to the Moon one correction, an adjustment of the flight trajectory, was carried out in all. On September 17 the spacecraft reached the specified region of the Moon, and its orientation system placed the spacecraft into the position necessary for turning on the retrorocket. After termination of the rocket's operation, Luna-16 went into a selenocentric orbit with an altitude at aposelene of 110 km. On September 20 at 8 hours 18 minutes the spacecraft began to descend in order to carry out a soft landing on the lunar surface. During its descent the spacecraft was in a strictly determined position which was accomplished by the stabilizing units of the control system. The rate of descent and the altitude above the lunar surface were strictly controlled. At an altitude of 20 m when the main motor of the descent stage was turned on, the precision descent mode began with the help of low-thrust motors which provided for the landing of the spacecraft on the lunar surface with practically zero velocity.

After the spacecraft's landing, its location in the Sea of Fertility was precisely determined. Then operations began with the soil-sampling device. Control of the operation of the soil-sampling device was accomplished by an operator on command from the Earth. The operations were carried out in the following sequence: first the lock which fixed the soil-sampling device in flight was opened, and the rod with the drill machine took a

vertical position; then the rod was turned by 180°.

This operation provided for the deployment of the rod in the horizontal position and the turning of the working part of the body of the drill machine in the direction of the lunar surface. The last operation was accomplished by the contact of the machine with the lunar surface.

Drilling of the lunar soil was accomplished with a special drill. The drilling rate and control of it permitted estimating the firmness of the soil at the drilling site. After completion of the operation, the drill with the lunar material was removed /43
to a special container located in the return stage and emptied from the drilling machine. The container with the lunar soil was hermetically sealed. Thus the first and main stage of the operations of the Luna-16 spacecraft, namely, the automatic sampling of the lunar soil, was completed.

The second stage, the launch from the Moon, was no less important, and in its engineering complexity it is a unique example of the application of automatic control systems in space research.

The value of the velocity which the spacecraft should acquire upon its ascent from the Moon was transmitted to the ascent stage, and the parameters were specified for the orientation and control systems along with other parameters for placing the spacecraft into a flight trajectory towards the Earth. The flight along the Moon-Earth route was carried out along a ballistic trajectory. Upon approaching the Earth the instrument compartment was separated from the return device which entered the dense layers of the atmosphere with escape velocity. Protective thermal devices maintained the safety of the return

device from high temperatures. In spite of the huge overloads, the instrumentation of the return device operated normally. At an altitude of 14.5 km the drogue parachute was opened, and then the main parachutes, and a direction-finding device was turned on with the help of which it was possible to track the spacecraft's descent to the Earth's surface right up to the moment of its landing.

On September 24 at 8 hours 26 minutes the return device completed its landing 80 kilometers southeast of the city of Dzhezkazgan. A search party located the container with the lunar soil from the return stage and brought it to a special laboratory of the USSR Academy of Sciences for careful analysis. Thus was completed the historic flight of the Luna-16 spacecraft. Thus for the first time in the history of cosmonautics an automatic spacecraft succeeded in reaching the surface of another celestial object of the solar system, landing there, sampling the soil, launching itself from the surface, and returning to the Earth.

Investigation of the Moon by automatic spacecraft was continued by the launch on November 10, 1970 of the Luna-17 spacecraft.

On November 17 the Luna-17 spacecraft completed a soft landing on the lunar surface in the region of the Sea of Rains. A self-propelled lunar device, Lunokhod-1, was mounted on the landing stage. After the landing, checking of the operation of the spacecraft's onboard systems, and an inspection of the lunar surface, the Lunokhod-1 automatic device emerged from the Luna-17 spacecraft along a special ladder on November 17 at 9 hours 28 minutes, Moscow time, on command from the Earth. The movement across the Moon of the self-propelled device was accomplished with /44
the help of an 8-wheeled chassis. Flags and pennants with an

image of the national emblem of the Soviet Union and with a bas-relief of V. I. Lenin were mounted onboard the Lunokhod-1 and the landing stage.

Lunokhod-1 was equipped with various scientific instrumentation: television for the transmission to Earth of panoramic photographs, an x-ray telescope, cosmic-ray counters, and devices for studying the properties of the lunar soil. In accordance with a Soviet-French agreement on cooperation in the investigation and conquest of outer space for peaceful purposes, a French reflector was mounted onboard Lunokhod-1 for laser location of the Moon.

The creation of Lunokhod-1 is the greatest achievement of Soviet space and rocket technology, which opens up broad possibilities not only for the direct investigation of the Moon, but, using the Moon as a support base, permits carrying out various astronomical investigations without atmospheric interference. Thus step by step a new world is mastered which will belong to all mankind.

The flights of spacecraft and spaceships to the Moon during the last ten years have enriched mankind with such a volume of information which exceeds by far all that was previously known about the Moon. The first fundamental data were obtained as a result of the photography of the lunar surface and especially of the investigation of the panoramic photographs transmitted to the Earth by the Luna-9 and 13 and the Surveyor spacecraft. Deciphering of the photographs revealed many distinctive features of the structure of the far side of the Moon: the highland nature of the surface with an increased density of craters and the absence of extensive maria regions. On the basis of the photographs obtained, a single system of selenographic coordinates

has been extended to both hemispheres of the Moon.

In 1960 in the USSR the first Atlas of the Far Side of the Moon was published, which contained the first map in the history of lunar research which depicted the far side of the Moon at a scale of 1:10,000,000. The Atlas contained about 400 of the largest features located in the eastern and central parts of the Moon. In 1967 in the USSR the second part of the Atlas of the Far Side of the Moon was published, in which a map of the western part of the invisible hemisphere of the lunar surface at a scale of 1:5,000,000 was contained on nine plates. A grid of selenographic coordinates is attached to each photograph, and reference points are denoted by special symbols.

On the basis of the information obtained by the Luna-3 and Zond-3 spacecraft and the contemporary photographic atlases of the Moon, the first map was compiled in the USSR of the entire surface of the Moon at a scale of 1:5,000,000, the entire lunar globe at a scale of 1:10,000,000 and a photographic map of the Moon's visible side at a scale of 1:5,000,000. /45

Circular panoramas of the lunar surface obtained at various solar altitudes permitted seeing lunar relief just as it would be seen by a man located directly on the Moon. The resolution of the images was of the order of a millimeter. The surface of the Moon appeared to be very porous and to have many small depressions and mounds. Separate rock formations about 15 cm in size and larger are scattered around.

Depressions several meters in size are clearly visible in the photographs. The surface of the Moon is covered by a layer of loosely bound grayish-brown material of varied grain size.

Still looser is a thin layer of dust discovered on the daytime part of the lunar surface. The dust rises due to the effect of the gas jets of the retrorockets upon the landing of spacecraft on the Moon's surface.

Neil Armstrong transmitted to Earth: "I sink into the soil about a fraction of an inch in all ... but I clearly see the tracks of my boots." The upper layer of the lunar soil has turned out to be loose and easily yielding to penetration, i.e., to penetrate into it. Its thickness has also turned out to be varied. Solid rocks or large fragments serve as the foundation for the surface layer. Rocks may be located very near the Moon's surface and may even stick to its surface. The entire surface of the Moon exists under special conditions completely unreproducible on the Earth: the space vacuum, continuous blowing by the solar wind, the action of ultraviolet radiation, and a number of other factors.

This situation leads to the fact that small particles of lunar soil can stick together to form larger particles under the effect of intermolecular forces, and they can adhere upon contact to the surface of other objects, significantly altering their optical properties.

The specific weight of the upper layer of the lunar surface within the first 15 - 20 cm is equal to 1.0 - 1.5 g/cm^3, and the soil angle of internal friction, or its shear resistance amounts to from 30 to 40°; the cohesion within the limits of the upper few centimeters of the surface layer amounts to $\sim$ 0.0013 - 0.0120 kg/cm^2, and the static bearing capacity is of the order of 0.18 - 0.68 kg/cm^2 at this depth, and an order of magnitude lower at the surface itself. The porosity coefficient is 0.87 - 0.01, which corresponds to a porosity of the material of 46.5% - 50.1%.

Study of the chemical composition of lunar rocks began with the help of a gamma-spectrometer mounted on the first artificial satellite of the Moon, the Luna-10 spacecraft. Gamma-spectrometer measurements of the Moon are associated with the presence in the /46
lunar rocks of radioactive elements: thorium, uranium, and the isotope calcium-40. Study of the gamma-spectra obtained permitted a group of Soviet scientists under the direction of Academician A. P. Vinogradov to arrive at a fundamental conclusion: the amount of radioactive elements in the lunar material corresponds to their content in terrestrial rocks of basic composition, mainly, basalts. Such a conclusion was drawn with respect to the lunar maria.

With the help of an x-ray photometer mounted on the Luna-12 spacecraft, it was possible to detect comparatively weak x-ray radiation originating from the Moon's surface and to establish its nature.

This radiation is emitted by magnesium and aluminum atoms contained in the lunar soil and is excited under the action of short-wavelength solar radiation (S. L. Mandel'shtam).

Element-by-element chemical analysis of the lunar material was carried out by the Surveyor-5, 6 and 7 spacecraft with the help of the alpha-particle and proton radiation of lunar rocks excited by a special source. Data on the chemical composition of lunar rocks are presented in the final summary report on the Surveyor program.

A new stage in the experimental investigation of the Moon began after the landing on its surface of the crews of the Apollo-11 and Apollo-12 spaceships in the region of the Sea of Tranquility and the Ocean of Storms. The crews of these ships

TABLE 4

Chemical elements	Atomic content by %			
	Surveyor-5		Surveyor-6	Surveyor-7
	Sample 1	Sample 2		Sample 1
Carbon	<3	<3	<2	<2
Oxygen	58 ± 5	56 ± 5	57 ± 5	58 ± 5
Sodium	<2	<2	<2	<3
Magnesium	3 ± 3	3 ± 3	3 ± 3	4 ± 3
Aluminum	6.5 ± 2	6.5 ± 2	6.5 ± 2	9 ± 3
Silicon	18.5 ± 2	19 ± 3	22 ± 4	18 ± 4
Calcium group	-	-	6 ± 2	6 ± 2
Iron group	-	-	5 ± 2	2 ± 1

collected samples on the lunar surface of lunar rocks and the finally dispersed material and returned them to the Earth in special containers.

The third region from which lunar material was returned to the Earth with the help of the Luna-16 spacecraft was the Sea of Fertility.

Apollo-11 completed a landing on the lunar surface in the /47
southwest part of the Sea of Tranquility (selenographic coordinates: 0.67° N. Lat. and 23.49° E. Long.).

Analysis of the lunar soil confirmed first of all all the main conclusions of its composition, structure, and mechanical properties derived prior to this event with the help of automatic spacecraft. Moreover, direct study of the lunar rocks under

laboratory conditions permitted obtaining a number of new interesting data. (The results of the preliminary investigation of the lunar material returned by the American astronauts are published in the journal, Science, Vol. 167, No. 3918, p. 167, No. 3923, 1970.) It was possible to distinguish four main types of rocks: fine-grained porous igneous rocks (Type A), coarse-grained igneous rocks (Type B), breccias (fragments of igneous rocks and minerals, many of which have been subjected to melting as a result of meteoric impacts), and regolith (fine particles, dust). The first three types of rocks have turned out to be identical in their chemical composition. Concerning the regolith, this type of rock has proven to contain admixtures of meteoritic material and, evidently, materials characteristic of the lunar highlands. Analysis has shown that the rocks from the Sea of Tranquility (Apollo-11) contain: 40 - 45% oxygen, 17 - 21% calcium, 4 - 7% aluminum, and approximately 4 - 6% titanium and magnesium, which has caused a sensation in the scientific world. However, the rocks returned from the Ocean of Storms (Apollo-12) contained on the average 2 - 3 times less titanium and have less sodium, zirconium, barium, and rubidium.

At the same time somewhat more magnesium, cobalt, vanadium, and scandium has been detected in them. Thus based on the composition of the main rock-forming elements, the composition of the lunar soil from various regions of the Moon differs little.

We speak of the agreement or discrepancy of the chemical composition of lunar and terrestrial rocks; all the investigated samples have proven to be different from terrestrial rocks. The point is that in comparing rocks it is necessary to take into account not only the chemical composition but also the main constituent minerals, their content, and structure. The principal minerals of lunar rocks are ilmenite, plagioclase, and

clinopyroxene, and in insignificant amounts, olivine. However, based on the extent of the granularity lunar rocks differ significantly from each other. For example, the grains of olivine are up to 0.5 mm, and the size of the grains of other minerals varied between 0.05 and 0.2 mm in diameter. All the rocks investigated, with the exception of opaque minerals (ilimenite), resemble certain terrestrial olivine-containing basalts.

The grain size in Type B rocks varies from 0.2 to 0.3 mm. Particles of glass, which are the main constituent of the breccias, resemble glass of thin lunar material. The nonuniformity of the /48 glass comprising the particles has been pointed out, which is completely uncharacteristic of terrestrial volcanic glasses. Traces of shock metamorphism are present in the lunar samples, especially in the loose and fine-grained material and breccias. At the same time crystalline rocks in the inner parts have not experienced shock metamorphism. Many pecularities in the loose material and breccias are evidently associated with the melting of the material under extreme shock.

The surface layer of lunar material, the lunar dust, is of particular interest. As investigations have shown, its main constituents are tips of rocks and fragments of crystals, dark glass containing numerous iron-nickel inclusions, and transparent glass of uniform composition. The smaller the size of the dust particles, the larger the amount of vitreous material in them. Located in a deep space vacuum in the absence of water and oxygen, the particles of lunar dust are capable of adhering (so-called adhesion). However, the bearing strength of the dust is not high due to the large number of small glass spheres among its particles, which produce a low frictional resistance.

THE PHYSICAL PROPERTIES OF LUNAR ROCKS

Experiments have been carried out to determine the remanent and induced magnetization of the lunar rocks. The remanent magnetization for a sample of lunar breccia proved to be 7.7×10^{-3} cgs units/g, and the induced magnetization in a field of 0.92 oersteds was equal to 7.6×10^{-3} cgs units/g.

Thermal magnetic investigations (as to the value of the Curie point) were carried out for lunar rocks of several phases: irons with $\sim$ 1% Ni (igneous rocks), irons with $\sim$ 5 - 10% Ni and $\geq$ 33% Ni (meteoritic), and also ilmenite.

The Curie point for samples of vesicular basalt, fine-grained basalt, and a number of other rocks turned out to be within the range 680 - 780° K, and the remanent magnetization was $8.4 \times 10^{-5} - 0.3 \times 10^{-5}$ cgs units/g. A breccia sample (18.5 g) was investigated by the methods of paleomagnetism. As a result it was discovered that the remanent magnetization was $\sim 3.7 \times 10^{-4}$ cgs units/g, the volume magnetic susceptibility was $\sim 6.3 \times 10^{-3}$ cgs units and the Curie point was $\sim$ 750° K.

The magneto-resonance properties were determined for various rocks and samples of finely divided material. The experiments were carried out at frequencies of 9 and 35 Hz at various temperatures. At these frequencies the material exhibited strong absorption at g = 2 where $g = h\nu/\beta H$ with a line width of $\sim$ 950 gauss. Such a resonance is caused by iron ions with strong exchange interactions. Resonances were detected which are caused by other ions, and also a number of important magneto-resonance properties of the lunar material were investigated. /49

Natural thermoluminescence was discovered in the lunar samples, and the emission peak for finely divided material and breccias was found at a temperature of $\sim 350°$ K and at $T \geq 400°$ K for crystalline rocks. It was discovered that the main carrier of thermoluminescence is the mineral plagioclase. The total thermoluminescence energy turned out to be $\sim 8 \times 10^{-9}$ cal/g for finely divided rocks and $\sim 2 \times 10^{-9}$ for the breccias. On the basis of the emission curves it was shown that the diurnal temperature wave on the Moon penetrates to a depth of ~ 10.5 cm. The lunar dust, which is bombarded by protons with an energy of ~ 60 keV, gives weak luminescence but it is not detected upon ultraviolet irradiation. The breccias exhibit luminescence in both cases. Neither dust nor fragments were detected with natural or excited thermoluminescence.

The luminescence was studied in six different samples. The efficiency of luminescence excitation was very low. In the case of proton and ultraviolet irradiation the value of the excitation efficiency was $\geq 10^{-6}$. If this value is typical for the Moon, the detection of the lunar surface's luminescence is evidently impossible in practice.

The polarization properties of the dust in the Sea of Tranquility turned out to be identical to those which were discovered on the basis of ground-based observations.

The reflectivity of the lunar samples in the $\lambda\lambda$ 0.5 - 2.0 micron range and for visible light was measured at angles of incidence up to 60°, and the material's thermal conductivity was also determined in the temperature range 200 - 400° K in a vacuum. It was discovered that the reflectivity for visible light increases as the angle of observation increases, the spectral reflectivity of powder and basalt monotonically increases as the wavelength

increases, and minima are clearly exhibited in the reflection spectrum for the breccias at a wavelength of λ 1 micron and for wavelengths >2 microns but only at a wavelength of λ 1 micron for crystalline rocks. The thermal conductivity of the powder with $\rho = 1.265$ g/cm^3 turned out to be $\sim 1.71 \times 10^{-3}$ watts/m° K at 205° K, 2.07×10^{-3} at 299° K and 2.42×10^{-3} at 404° K. The absorption properties of the lunar rocks were investigated in the infrared wavelength region of λ 2 - 2000 microns.

Measurements were carried out of the specific heat capacity and thermal conductivity of the samples. The heat capacity of the breccias was 0.20 ± 0.02 cal·g^{-1}·°K^{-1}, and the thermal conductivity for the finely divided material was 2.5×10^{-6} cal·cm^{-1}·°K^{-1}·sec^{-1} and $\sim (0.5 - 2.0) \times 10^{-3}$ cal·cm^{-1}·°K^{-1}·sec^{-1} /50 for the crystalline rocks and the breccias, which is significantly less than for terrestrial rocks. At atmospheric pressure and a temperature of 0° the specific thermal conductivity and the thermal inertia of the fine-grained vesicular crystalline rocks were equal to 3.87×10^{-3} cal/cm·sec.°K and 22 cm^2·sec$^{1/2}$· °K/cal, respectively, and 1.66×10^{-3} and 40 for the breccia. The specific heat capacity at a temperature of from 90 to 350° K for a vesicular basaltic-like rock and for finely divided material were very similar, namely, from 0.06 cal·g^{-1}·°K^{-1} at T = 90° K to 0.2 cal·g^{-1}·°K^{-1} at T = 350° K. Thus, for the combination of parameters $\gamma = (K\rho C)^{-1/2}$, where K is the thermoconductivity, ρ is the density, and C is the heat capacity, values from 34.33 at T = 100° K to 19.41 at T = 350° K are obtained for basaltic rock and from 1543 to 898 for finely divided material.

Study of the elastic properties of lunar rocks is very important from the point of view of the Moon's internal structure. Study of the Moon's interior is possible, for example, by investigating the propagation of seismic oscillations and their

velocities, which are expressed in terms of the elasticity coefficient: $v_p \rho^{1/2} = (\lambda+2\mu)^{1/2} \times v_s \rho^{1/2} = \mu^{1/2}$ (λ, μ are the elastic constants). The velocities of the longitudinal (P) and the transverse (S) elastic waves were measured in lunar samples at pressures of up to 5 kilobars. The results of the measurements are given in Table 5.

TABLE 5.

Sample	Wave	Pressure, kilobars						
		0,0	0,5	1,0	2,0	3,0	4,0	5,0
$\rho = 3{,}8$ g/cm^3	P	3,50	4,80	5,55	6,30	6,80	7,00	7,20
	S	2,20	2,88	3,25	3,67	3,87	4,00	4,08
$\rho = 2{,}8$ g/cm^3	P	2,82	3,80	4,65	5,62	6,18	6,52	6,78
	S	1,70	2,45	2,82	3,20	3,39	3,50	3,62
$\rho = 2{,}3$ g/cm^3	P	1,50	2,90	3,50	4,05	4,30	4,40	4,50
	S	1,05	1,70	2,00	2,28	2,42	2,65	2,78

*Translator's Note: Commas represent decimal points.

As the measurements show, the damping coefficient for seismic waves is very large (Q = 10) for pressures less than 0.2 kilobar.

Searches for organic material have shown that its content does not exceed $\sim 10^{-4}\% - 10^{-5}\%$. No objects of biological interest were discovered in the materials investigated.

We will briefly formulate the conclusions which the American scientists have drawn on the basis of the preliminary analysis of the lunar rocks returned to the Earth by the crew of the Apollo-11 spaceship. /51

1. On the basis of their mineralogical composition and structure, the lunar rocks are divided into two groups:

a) Fine- and average-grained crystalline rocks of igneous origin. The igneous rocks are basalts composed of pyroxene, plagioclase, ilmenite, olivine, and cristobalite. The crystallization of these rocks occurs under very dry highly reducing conditions ($P \sim 10^{-33}$ atm). The temperature range of crystallization is 1210 - 1060°. The crystallization of the igneous rocks occurred from $3 \cdot 10^9$ to $4 \cdot 10^9$ years ago, and the rocks were located at a depth of no more than 1 meter from the surface for a period of from $20 \cdot 10^6$ to $160 \cdot 10^6$ years. The crystalline rocks differ somewhat on the basis of their mineral and gross chemical composition from any terrestrial rocks and meteorites.

b) Breccias with a complex history.

2. Erosion processes occur on the Moon's surface. The rate of surface erosion of the rocks is estimated at 10^{-7} cm/year. No signs have been detected of water erosion. Thus many millions of years are necessary for a spaceship, for example, to be converted to dust on the Moon.

3. Secondary water-bearing minerals are absent, i.e., there was never any water at the Apollo-11 spaceship's landing site from the moment of formation of the rocks.

4. There were signs of the action of shock metamorphism on the lunar rocks and the fine material.

5. Traces were noticed in almost all the lunar rocks of the bombardment of their surface by small particles.

6. The thin material and the breccias contain noble gases in sufficient amount, which were captured from the solar wind.

7. Study of the tracks of nuclear particles and the induced radioactivity of the samples shows that the bombardment of the lunar surface by particles of the solar wind (and also by galactic cosmic rays) was uniform without noticeable variations during an extended period of time.

8. The radiation age of the rocks is $\geq 10 \cdot 10^6$ years at a depth of several centimeters and $\geq 500 \cdot 10^6$ years at a depth of 1 - 2 meters.

9. All the rocks and soil investigated are very similar to each other on the basis of their chemical composition.

10. Based on the chemical elements present, the lunar rocks differ little from terrestrial rocks and meteorites; however, significant differences exist with regard to their composition: the lunar rocks are enriched in the elements which form refractory /52 bonds and are depleted in the alkalis.

11. The concentrations of uranium and thorium are similar to those in terrestrial basalts. However, the potassium/uranium ratio of 2400 - 3200 is unusually low for the lunar rocks in comparison with chondrites (45,000) and terrestrial rocks (10,000). One can assume a constant value of this ratio for the Moon as a whole.

12. The oxygen content in the samples is $(50\text{-}25) \times 10^{-6}$ g/g.

13. No signs of any biological material have been detected in the lunar rocks.

14. Based on their mechanical characteristics the lunar rocks are very similar to the properties which were derived earlier with the help of unmanned spacecraft.

15. The thermal conductivity of the dust layer was approximately 1000 times less than that of the original rocks.

16. The optical, electromagnetic and thermophysical properties of the lunar material were investigated. The possibility of the formation of a seismic wave guide in the Moon's upper layers was established in principle.

The most significant discoveries and conclusions which were made on the basis of the derived results are:

1. The discovery of erosional properties on the Moon.

2. The absence of analogs among terrestrial rocks to lunar rocks with respect to their chemical composition.

3. The establishment of the ancient age of the igneous lunar rocks, i.e., some lunar rocks were crystallized earlier than the most ancient terrestrial rocks.

On November 19, 1969 the Apollo-12 spaceship executed a landing in the region of the Ocean of Storms approximately 120 km southeast of the crater Lansberg with the coordinates 23°34' W and 2°45' S.

The landing site was located on a broad ray of the crater Copernicus.

During their stay on the Moon the astronauts collected 45 kg of lunar rock samples, which were then subjected on the Earth to physical, chemical, mineralogical, and biological analysis.

The main conclusion which the American scientists drew reduces to the following: the properties of the lunar rocks returned from the Sea of Tranquility agree essentially with the properties of the lunar rocks returned from the Ocean of Storms with the following exceptions:

1. The crystalline rocks from the Ocean of Storms are characterized by more extensive variations both in their structure and in their mineralological composition.

2. The igneous rocks from the Ocean of Storms are evidently /53
parts of a single intrusive series or represent a number of similar series.

3. The relative amount of breccias in the Ocean of Storms is less than from the Sea of Tranquility, since the regolith thickness in the Ocean of Storms is only half as large as in the Sea of Tranquility. At the same time the stratification of the regolith from the Ocean of Storms is more complex.

4. Carbon is contained in larger amounts in the breccias and the finely divided material than in the crystalline rocks.

5. The amount of organic material is very low (1 - 20) X 10^{-6}%.

6. The amount of noble gases, which are formed as a result of the interaction of the solar wind with the lunar surface, in the breccias and the finely divided material is lower in the Ocean

of Storms in comparison with the Sea of Tranquility.

7. Fragments of lunar rocks were located at a depth of less than 1 meter from the surface for 1 - 200 million years.

8. The crystallization process occurred in the rocks from $1.7 \cdot 10^9$ to $2.7 \cdot 10^9$ years ago.

9. The breccias and finely divided material are very similar in their chemical composition; however, the amounts of titanium are only half as large in them as in the samples from the Sea of Tranquility.

10. The material returned from the Ocean of Storms is younger than the material from the Sea of Tranquility. A determination of the potassium-argon age is an estimate of one billion years which agrees in general with the geological data. This result indicates that the maria on the Moon were formed during an extended period of time.

The third region from which lunar material was returned to the Earth by the Luna-16 spacecraft is the Sea of Fertility. The lunar soil was taken by the spacecraft at a point with the coordinates 0°41' S. and 56°18' E. approximately 900 km east of the landing site of the Apollo-11 spaceship and 2500 km from the landing site of Apollo-12. The lunar soil was returned to the Earth in the form of loose material which consists on the whole of a dark gray powder of various grain sizes. The sample is composed of large-grain material only at the base of the sample at a depth of 35 cm. The total weight of the soil column was somewhat greater than 100 g.

The lunar soil material easily sticks together into separate loose features which distinguishes it from the terrestrial unstructured dust. It resembles moist sand or the crumbled structure of terrestrial soils. The granularity of the soil increases with depth along the column's length and it is possible to distinguish on the basis of this characteristic several zones which succeed each other: a zone of fine-grained material with a low content of coarse fractions (0 - 15 cm of the column's length); a zone of varied grain size material including fragments of rocks and other particles with a size greater than 3 mm (15 - 33 cm of the column's length); and a zone of coarse-grained material (33 - 35 cm of the column's length). The optical properties of the lunar surface are mainly determined by the first zone. The average specific weight of the soil in its natural attitude with respect to the depth of penetration of the drill was determined to be 1.2 g/cm^3 and 1.8 g/cm^3 upon being shaken down. Thus the soil porosity at a depth of 35 cm was determined to be 50 - 60%. /54

An entire series of particle groups were separated out from the coarser fractions and investigated: basaltic rocks, feldspars, sedimentary materials, frozen spherical droplets, breccias, sinters, glasses, glass-like and slag particles, and particles of metallic iron. Based on the chemical composition of the lunar soil material, these particles represent pulverized rock of basaltic type. Already 70 chemical elements and isotopes have been determined in the composition of the lunar rocks returned by the Luna-16 spacecraft. Chemical analysis of the basaltic rock and the fine fraction of lunar material returned by the Luna-16 is given in Table 6 along with a comparison of it with the lunar material returned by Apollo-12.

TABLE 6*

Composition	Basaltic Luna-16 rock	Luna-16 fine fraction	Apollo-12 basaltic rock	Apollo-12 fine fraction
SiO_2	43,8	41,7	40	42
TiO_2	4,9	3,39	3,7	3,1
Al_2O_3	13,65	15,32	11,2	14
FeO	19,35	16,8	21,3	17
MgO	7,05	8,73	11,7	12
CaO	10,4	12,2	10,7	10
Na_2O	0,33	0,37	0,45	0,4
K_2O	0,15	0,10	0,065	0,18
MnO	0,2	0,21	0,26	0,25
Cr_2O_3	0,28	0,31	0,55	0,41
ZrO_2	0,04	0,015	0,023	0,09

*Translator's Note: Commas represent decimal points.

If we compare the lunar rocks returned by the Apollo astronauts and by the Luna-16 spacecraft with respect to their chemical composition, it nevertheless appears that the latter are closer to the lunar material returned by the Apollo-12 astronauts, as is immediately evident from Table 6.

The problem of the origin of the lunar rocks still remains a difficult one; however, it is already possible to speak of the role of various processes occurring in the history of the Moon. As Academician A. P. Vinogradov writes, "... the crystalline rocks from the surface of the lunar maria are of a single basaltic type, but they differ somewhat with respect to the amount of certain chemical elements. Their composition approaches the composition of the primitive basalts of the Earth. The lunar maria are plains once flooded by volcanic lava. Rocks /55
of basaltic type are formed as the most easily melted part upon zonal melting of a planet's interior material. One can assume that the general run of differentiation of the material of the

Earth and the Moon, and probably of the other planets of the terrestrial type, proceeded in similar ways, although it reached different stages of development"[3].

HYPOTHESES OF THE MOON'S ORIGIN

Formerly one of the disturbing cosmogonical puzzles was the question of the Moon's origin. At various times three theories were advanced, on the basis of which the origin of the Moon was discussed. According to the first theory the Moon was formed simultaneously with the Earth from a single gaseous or dust space cloud. The Moon in comparison with its central object (the Earth) is the largest satellite with respect to its mass of all the satellites of the planets of the solar system.

Because of this amazing fact, the Moon and the Earth have been considered as a double planet, but the mechanism of formation of such a double planet has not been worked out, which has resulted in the fact that the theory of the simultaneous formation of the Moon and the Earth is not uniformly accepted at the present time by astronomers and planetologists.

At the start of the present century the remarkable astronomer and mathematician George Darwin (the son of the great biologist Charles Darwin) advanced an interesting theory for the Moon's origin which was based on an investigation of the figures of equilibrium of a rotating liquid mass. It is known that this problem is a classical problem of mechanics which was studied by the greatest analytic mechanicians (Maclaurin, Clairaut, Jacobi, Poincaré, and others). Upon a slow rotation the liquid mass takes

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(3) The problem of the origin of lunar rocks has been discussed in greater detail by Academician A. P. Vinogradov in the journal Geokhimiya, No. 1, 1970.

on the shape of a spheroid flattened along the axis of rotation, and in the case of very rapid rotation, the liquid mass takes on a shape resembling a pear, the so-called pear-shaped figure of rotation. G. Darwin showed that the neck of the pear-shaped figure becomes thinner upon further evolution, and a dumbell-shaped object is formed with two centers (the Poincaré figure), and a rupture of the mass begins which in G. Darwin's opinion was the instant of the Moon's separation from the Earth. However, the problem of the stability of pear-shaped figures of rotation was not rigorously solved.

G. Darwin based his investigations on the work carried out by the eminent French mathematician Henri Poincaré on the figures of equilibrium of rotating liquid objects. Both scientists, /56
G. Darwin and H. Poincaré, arrived in their research at the conclusion that pear-shaped figures of equilibrium can exist. The rupture of the neck, i.e., the separation of the two centers and the independent existence of the objects formed, is possible only in the case where the pear-shaped figure is stable.

Simultaneously with G. Darwin and H. Poincaré the great Russian mathematician Aleksandr Mikhaylovich Lyapunov worked on the problem of the figures of equilibrium of rotating liquid objects. Another noted Russian scientist P. L. Chebyshev brought this problem to his attention. A. M. Lyapunov brought the solution of the problem posed to its conclusion and showed that pear-shaped figures of equilibrium are unstable. An argument developed between Darwin and Poincaré on the one hand, and A. N. Lyapunov on the other hand. This argument was finally settled in favor of the Russian scientist by the English astronomer J. Jeans in 1916, who proved the impossibility of the existence of a pear-shaped figure. The mechanism for the separation of the Moon from the Earth proposed by G. Darwin proved to be

unacceptable. In this case the separated second center (the Moon) would not be able to collect into a single mass and would be scattered in space.

The well-known Swedish astrophysicist and Nobel Prize winner H. Alfvén is the author of the third theory for the Moon's origin. H. Alfvén proposes that the Moon was initially an independent celestial object and rotated around the Sun along with the asteroids. At some instant of time the Moon approached the Earth and, due to the tidal effects caused by the Earth's attraction, changes in its axial rotation occurred on the Moon. Furthermore the attraction of the Earth and the Sun altered the orbit of the Moon, and it became a satellite of the Earth. Many physical and chemical data on the structure of the Moon and the planets of the solar system are necessary for the establishment of H. Alfvén's theory.

The idea of the Moon's formation in the solar system independently of the Earth and its capture by the Earth is supported by Harold Urey, the great geochemist and Nobel Prize winner. H. Urey assumes that the Moon is a primary object in comparison with the planets of the terrestrial group.

Thus we see that the problem of the Moon's origin is the greatest cosmogonical problem. The results which are presently being obtained in the investigation of the Moon by spacecraft have significantly shrunk the boundaries of possible hypotheses, but they do not permit the solution of all the problems. The investigation of the Moon's internal structure, the explanation of the origin of the Moon rocks, and the establishment of the exact age of the Moon will show to which class of planet or satellite the Moon belongs, which may serve as the key to the solution of the great problem of the origin of our entire solar system. /57

PHOTOGRAPHY OF THE SURFACE OF MARS

On July 14, 1965, the Mariner-4 spacecraft approached the planet Mars at a distance of about 30,000 km. A command was sent to the Earth from onboard the spacecraft to warm up its television scanning system. At a distance of 16,800 km the planet detector, which is based on the sunlight reflected from Mars, turned on the photographic equipment. During the next 26 minutes 22 photographs of the Martian surface were taken. During this time Mariner-4 approached the planet to within 11,800 km. The spacecraft approached nearest to Mars, a distance of ∿9850 km, 18 minutes after completing the photography session. Mariner-4 disappeared behind the planet's disk in another 1 hour 18 minutes, and communication with the spacecraft was interrupted for 54 minutes. The slow transmission of the images of the surface of Mars began 11 hours after the last photograph was taken. The pictures were transmitted in binary code at a rate of ∿ 8.33 bits/sec. The transmission time of a single picture was 8.66 hours. On July 24, 1965 all the pictures had been transmitted to the Earth from onboard the Mariner-4 spacecraft. Two hundred and forty thousand binary units of information were required for the transmission of each picture.

The slow rate of transmission was caused by the enormous distance from the Earth (more than 214 million km) at which the spacecraft was located. The pictures of the surface of Mars were transmitted through red or green filters. In all Mariner-4 succeeded in photographing ∿1% of the planet's surface with a total area of about 1,500,000 square kilometers. The length of a scanning strip was equal to approximately 6500 km and passed across the equator from the northern hemisphere to the southern. During the photography the illumination varied from complete subsolar illumination to complete darkness. The photographs

were decoded by a team of scientists headed by Leighton at the Jet Propulsion Laboratory (Pasadena). The most interesting photographs turned out to be the 11 from No. 5 to No. 15. On picture No. 5 Martian craters similar to those which are observed on the Moon's surface were first detected. This discovery belongs to the list of the greatest scientific achievements of our century. A crater was detected on picture No. 11 which has a diameter of about 180 km, and craters with diameters down to 5 km are also visible. The entire area occupies approximately 270 X 240 km.

Craters were detected on the other pictures with walls covered by hoarfrost (it was winter in the southern hemisphere at this time). The flight of the Mariner-4 spacecraft imparted /54
significant stimulation to the continuation of the investigations of Mars by photographic methods.

In 1968 the Mariner-6 and 7 spacecraft were directed towards the planet Mars. On July 31 and August 5, 1969, respectively, they reached the vicinity of Mars and carried out photography of its surface. The photographic television system was significantly improved, and the rate of data transmission was increased by several orders of magnitude ($\sim 16.2 \cdot 10^3$ bits/sec). Two cameras, A and B, were located onboard each of the spacecraft (A with a focal distance of f = 52 mm, and B with a focal distance of f = 508 mm).

Thirty-three images of the planet's entire disk were obtained by Mariner-6 with the help of the narrow angle television camera at the spacecraft's distant encounter with the planet, and then 17 more images were obtained. During the 18 minutes at the period of near encounter (6000 km) the photography was carried

out alternately by cameras A and B mainly in the equatorial zone of Mars. The number of images obtained at near encounter by the two cameras amounted to 26.

With the help of the photographic television equipment of the Mariner-7 spacecraft, 93 images were obtained at far encounter and 33 at near encounter. In addition, the mode of direct reception of the images was implemented. In this mode more than 1000 useful images transmitted from onboard Mariner-6 and 7 were obtained.

Analysis of the photographs of the surface of Mars obtained during the flyby of the planet by the Mariner-4, 6, and 7 spacecraft has opened up a new picture of the structure of the Martian surface unexpected by astronomers. The Martian surface has proven to be covered by craters of various sizes, closely resembling the surface of the Moon. It is possible to distinguish on Mars three kinds of regions which differ from one another with regard to their structure: 1) regions covered by craters, 2) regions with chaotic structures and 3) structureless zones.

A continuous transition in crater dimensions has not been discovered on Mars on the basis of the space photography data, which significantly distinguishes the Martian craters from lunar craters. A possible reason for this peculiarity is the weathering and transport of soil particles. Another important peculiarity of the Martian surface relief is its smoothness and nonuniformity (the transistion from regions with a large number of craters to regions where there are almost no craters). One can postulate that the structureless zones on Mars are the analog of terrestrial deserts. The structure of the Martian surface does not reveal any kind of typical distinctive features (for example, structures with sharply distinct albedo). It is noted

that craters are completely absent in the zone of chaotic structures. On the basis of the analysis of the television images /59
the group of American scientists headed by Leighton advanced some ideas with respect to the evolution of Mars as a planet.

Some relief shapes are absent on the surface of Mars which would be associated with the action of internal forces. Such forces, which act on the Earth, have significantly transformed and continue to transform the terrestrial surface. Thus it is possible to assume that an atmosphere of terrestrial type could never develop on Mars if we assume that the terrestrial atmosphere was formed in connection with tectonic processes of the differentiation of the Earth's crust.

A large number of large craters have been discovered on Mars which maintain their outlines and shapes well. This fact indicates that they developed almost simultaneously and were not subjected to water erosion, i.e., there has evidently never been a large amount of water on Mars. On the other hand, it should be pointed out that there are significantly fewer craters on Mars with diameters of 20 - 50 km than on the Moon. Therefore one can assume that the effect of erosion was a significant factor in the chaotic and structureless regions where the large craters were "erased" for unknown reasons.

The study of the Moon and the planets of the solar system by spacecraft is continuing successfully, and this has become especially clear since the splendid flights of the Luna-16 and Luna-17 spacecraft. The landing on the Moon's surface of the Lunokhod with an automatic navigation system and the control of its motion opens up enormous prospects for the investigation of distant celestial objects. This will evidently become the general line of development of comonautics over the next few decades.

One can say with complete truth that the successes of space technology have laid the foundations for a new direction in science, namely, experimental astronomy and planetology.

A SHOT INTO THE UNIVERSE — THE GRAND TOUR PROJECT

Various projects are presently being worked out for the further investigation of the Moon and the planets of the solar system, including the planets of the Jovian group, namely, Jupiter, Saturn, Uranus, Neptune, and Pluto.

The landing of the astronauts on the Moon, the successful solution of the problem of the automatic return of lunar material to the Earth, and the creation of the lunokhods all permit us to speak seriously of the conquest of the Moon and its detailed investigation. One of the promising directions in the conquest /60 of the Moon is the creation of lunar expeditions using lunokhods controlled by the astronauts or remotely on commands from the Earth. The use of lunokhods significantly broadens the possibilities of the study of the most varied regions of the lunar surface. The planning and designing operations provide for the creation of lunokhods with a crew and without a crew. With the help of the lunokhods with a crew, it is possible to solve the following problems:

1. topographical mapping of the elements of lunar relief;
2. study of the geological structure of the surface;
3. drilling of holes to a depth of 1 - 1.5 meters and the geological study of the subsurface layer;
4. magnetic and gravitational investigations;
5. geochemical investigations (recording the gamma radiation at the surface and in the drill holes at a depth of 1 - 1.5 m).

Contemporary methods of automatic control permit the creation of lunokhods without a crew which will simplify the solution of the most complicated problems on the Moon, including the transmission to Earth of television panoramas while in motion and also at the stopping places in the most interesting regions, and also vertical scanning above and below the horizon; the collection of geological samples, including probes with a depth of 1 - 1.5 meters, the study of the magnetic properties of the rocks with the help of a penetrometer, analysis of the samples with the help of an x-ray diffractometer (identification of minerals), and a spectrometer (determination of the elemental composition of the minerals); the setting up of seismographs for the study of the Moon's tectonic activity and the recording of the number of meteoritic impacts on the lunar surface, and gravimetric investigations.

At the present time a number of American companies, on the recommendation of NASA, have begun preliminary design studies. The lunar rovers planned, for example, by the Bendix and General Motors Corporations have received the designation LRV (Lunar Roving Vehicle — a lunar rover).

During the next decade the investigations of Mars and Venus will be continued by unmanned spacecraft. In 1971 the Americans planned to place artificial satellites with a period of revolution of 12 hours into orbits around Mars. Artificial satellites of Mars will permit solving a number of knotty problems in the investigation of Mars: the increase and shrinkage of the dimensions of the "polar caps", the advance of the "wave of darkening", and the formation and disappearance of clouds and dust storms. Photographic television instrumentation will be mounted on the spacecraft to photograph the surface of Mars; it is planned to photograph $\sim$ 70% of the surface with a resolution

of about 1 km. One of the main problems of this space experiment is to obtain data for the selection of landing sites for the descent stages of the Viking program. Some planned weight characteristics of this spacecraft are presently known. Its total weight amounts to 3,175 kg, including the orbital unit — 2,360 kg and the landing unit — 815 kg. The orbital unit includes the motor assembly with the help of which the transistion to an aerocentric orbit will be accomplished. The weight of the scientific instruments included in the orbital unit is ∿ 57 - 68 kg. It is proposed to land on the surface of Mars the descent stage with a weight of ∿ 180 - 360 kg, including 8.2 kg for instruments to investigate the atmosphere at the landing site and ∿ 10 kg for instruments for an investigation on the planet's surface. /61

The launch of two Viking spacecraft is planned for the end of the 1970's with a time span of 16 days. The spacecraft will reach the vicinity of Mars and will go into aerocentric orbits with an altitude at pericenter of no less than 2000 km. The inclination of the orbital planes of the Viking spacecraft should be ∿ 20 - 50° with respect to the plane of the Martian equator.

The descent stages will carry out landings on the surface of Mars between 30° N. and 20° S. on the basis of the preliminary data. The photographic television equipment which is located in the orbital unit is intended to refine the landing site of the descent stage, investigate the region where the descent stage carried out its landing, and also search for areas for subsequent promising investigations of Mars. Equipment should be mounted in the landing unit for panoramic mapping of the surface at the landing site, investigating the Martian soil, searching for water and organic compounds, determining the composition of

the atmosphere at the surface, studying the seismic activity, and for a number of biological investigations. It is assumed that during the descent phase data will be obtained on the vertical temperature and pressure distributions, and the gaseous composition of the Martian atmosphere will be determined at various altitudes. The electrical supply of the instruments of the landing unit will presumably be accomplished during the three months of its operation on the surface of Mars either by means of solar batteries or by the use of a radioisotope assembly with a thermoelectric energy conversion system.

One of the interesting directions in the investigation of the atmosphere of Venus will evidently be the development of a drifting balloon-probe. The balloon-probe is made of a plastic film and is about 5 meters in diameter. The probe is calculated to drift in the atmosphere of Venus at an altitude of $\sim$ 60 km. A television camera and scientific instruments are attached to the balloon-probe, along with detachable probes for carrying out scientific measurements in the lowest layers of the atmosphere. Retransmission of the data to Earth is accomplished through the main balloon-probe.

During the flight of the spacecraft to Venus the complex balloon-probe along with its scientific instruments is located /62
in a conical heat-protective casing. The casing is jettisoned in the atmosphere of Venus after the rate of deceleration reaches a value at which the balloon can be deployed.

The plan for successive flybys of a spacecraft past Venus and Mercury, with photography being carried out of the surface of the planet nearest to the Sun, is a very interesting one.

In 1972 - 1973 the first flights to the planets of the Jovian group are planned. To this end spacecraft of the Pioneer series are being developed for an investigation of the planet Jupiter with a flyby trajectory. The flight to Jupiter will last about 600 days. In order to avoid damage to the scientific instrumentation by the radiation of Jupiter's radiation belt, which evidently encircles the planet, the flyby of the spacecraft is planned to be carried out at a distance of 150,000 - 500,000 km from Jupiter. It is planned with the help of Pioneer spacecraft to carry out measurements of the parameters of the interplanetary medium and the asteroid belt between the orbits of Mars and Jupiter, make measurements of the nearest vicinities of the giant planets (magnetic field, intensity, temperature, and the direction of flow of the plasma and the shock wave of the radio emissions), photograph Jupiter in visible light, determine the extent of Jupiter's atmosphere above the cloud layer, determine the temperature of the nighttime side of Jupiter and thermal anomalies, and study the ratio of hydrogen and helium in Jupiter's gaseous envelope.

Due to a favorable arrangement of the giant planets at the end of the 1970's, the launch of a spacecraft is possible which will permit carrying out successive flybys past several of the outer planets of the solar system.

The principal version is a successive flyby past Jupiter, Saturn, Uranus, and Neptune, namely, the Grand Tour Project. Ballistic calculations show that a spacecraft launched from the Earth, for example, on September 4, 1977 will reach Jupiter on January 28, 1979, Saturn on September 30, 1980, Uranus on February 1, 1984 and Neptune on November 8, 1986. It is proposed that the spacecraft carry out its flyby on the inner side of the rings of Saturn. In this case the flight lasts 9.2 years. If the

flight trajectory passes on the outer side of the rings, the flight is increased to 11 years from the launching date.

The Grand Tour projects program has not yet been finally adopted. In addition, various versions of the program are possible, and they are enumerated in Table 7.

TABLE 7

Flyby past the planets	Favorable periods for the launch of a spacecraft					Next favorable period
	1976	1977	1978	1979	1980	
Jupiter, Saturn, Uranus, Neptune	X	X	X	—	—	2155
Jupiter, Saturn	—	X	X	X	—	1996
Jupiter, Uranus	—	—	—	X	X	1992
Jupiter, Neptune	—	—	—	X	X	1992
Jupiter, Pluto	—	X	X	—	—	1989
Jupiter, Uranus, Neptune	—	—	X	X	X	2155
Jupiter, Saturn, Pluto	—	X	X	—	—	2076

It is difficult to say which of the projects considered will be realized, but one thing is clear, and that is that mankind will strive continually to penetrate further and further into the depths of the universe, or as R. Tagor has said, "... it seems as if Truth appears with its last word: and the last word gives rise to a new word". /6

Mankind will see its own great "tomorrow" among its "today" only from the heights of this new word.

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